4. Mechanical Systems

4.1 Overview

The objective of the Standards requirements for mechanical systems is to reduce energy consumption while maintaining occupant comfort. These goals are achieved by:

1. Maximizing equipment efficiency, both at design conditions and during part load operation

2. Minimizing distribution losses of heating and cooling energy

3. Optimizing system control to minimize unnecessary operation and simultaneous use of heating and cooling energy

The Standards also recognize the importance of indoor air quality for occupant comfort and health. To this end, the Standards incorporate requirements for outdoor air ventilation that must be met during all operating conditions.

This chapter summarizes the requirements for space conditioning, ventilating, and service water heating systems. It is organized in 11 sections including this overview. The other sections are as follows:

- Section 4.2 Equipment Requirements addresses the requirements for HVAC and service water heating equipment efficiency and equipment mounted controls.
- Section 4.3 Ventilation Requirements includes mechanical ventilation, natural ventilation and demand controlled ventilation.
- Section 4.4 Pipe and Duct Distribution System covers construction and insulation of ducts and pipes, and duct sealing to reduce leakage.
- Section 4.5 HVAC System Control Requirements covers control requirements for HVAC systems including zone controls, and controls to limit reheat and recooling.
- Section 4.6 HVAC System Requirements covers the remaining requirements for HVAC systems including sizing and equipment selection, load calculations, economizers, electric resistance heating limitation, limitation on air-cooled chillers, fan power consumption and fan and pump flow controls.
- Section 4.7 Service Water Heating covers the remaining requirements for service water heating.
- Section 4.8 Performance Approach covers the performance method of compliance.
- Section 4.9 Additions and Alterations.

- Section 4.10 Glossary/Reference.
- Section 4.11 Mechanical Plan Check Documents describes the information that must be included in the building plans and specifications to show compliance with the Standards, including a presentation and discussion of the mechanical compliance forms.
- Section 4.11.8 Mechanical Inspection refers to the Inspection Checklist identifying the items that the inspector will verify in the field.

Acceptance requirements are new to the 2005 Standards. They apply at all times to the systems covered regardless of the path of compliance (for example an air side economizer, if provided, will always be tested even if it is not required for compliance). Chapter 8 describes mandated acceptance test requirements which are summarized at the end of each section. The full acceptance requirements are in §121, §122, §125, and in Appendix NJ of the Non-Residential ACM Manual.

4.1.1 HVAC Energy Use

Mechanical systems are the second largest consumer of energy in most buildings, exceeded only by lighting. The proportion of space-conditioning energy consumed by various mechanical components varies according to system design and climate. For most buildings in non-mountainous California climates, fans and cooling equipment may be the largest consumer of energy. Space heating energy is usually less than fans and cooling, followed by service water heating.

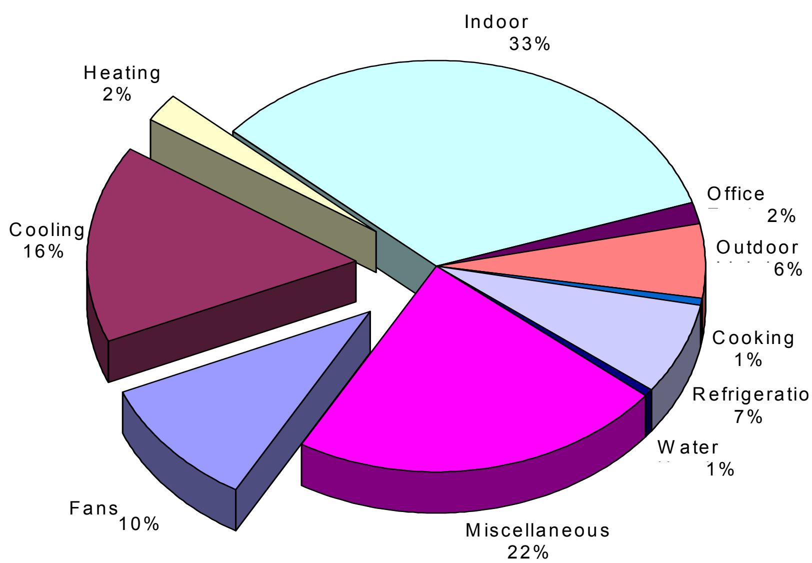

Figure 4-1– Typical Building Electricity Use
Heating, cooling and ventilation account for about 28% of commercial building electricity use in California. Source IEQ RFP, December 2002, California Energy Commission No. 500-02-501

4.1.2 Compliance Approaches

After the mandatory measures are met, the Standards allow mechanical system compliance to be demonstrated through prescriptive or performance requirements.

Mandatory Measures

Mandatory measures (§110-119 and §120-129) apply to all systems, whether the designer chooses the prescriptive or performance approach to compliance. Mandatory measures include:

- Certification of equipment efficiency (§110).
- HVAC and service water heating equipment efficiencies (§112 and §113).
- Ventilation requirements (§121).
- Demand controlled ventilation [§121(c)].
- Thermostats, shut-off control and night setback/setup (§122).
- Area isolation (§122).
- Duct construction and insulation (§124).
- Pipe insulation (§123).
- Acceptance tests (§121, §122, §125).
- Service water heating and pool heating measures (§113 and §114).

Prescriptive Requirements

Prescriptive measures cover items that can be used to qualify components and systems on an individual basis and are contained in §144. Prescriptive measures provide the basis for the Standards and are the prescribed set of measures to be installed in a building for the simplest approach to compliance. Prescriptive measures include:

- Load calculations, sizing, system type and equipment selection [§144(a) and (b)].
- Fan power consumption [§144(c)].
- Controls to reduce reheating, recooling and mixing of conditioned air streams; [§144(d)].
- Economizers [§144(e)].
- Supply temperature reset [§144(f)].
- Restrictions on electric-resistance heating [§144(g)].
- Fan speed controls for heat rejection equipment [§144(h)].
- Limitation on centrifugal fan cooling towers [§144(h)].
- Limitation on air-cooled chillers [§144(i)].
- Hydronic system design [§144(j)].

- Duct sealing [§144(k)].

Performance Approach

The performance approach (§141) allows the designer to increase the efficiency or effectiveness of selected mandatory and prescriptive measures, and to decrease the efficiency of other prescriptive measures. The performance approach requires the use of an Energy Commission certified computer program, and may only be used to model the performance of mechanical systems that are covered under the building permit application. (See Section 4.8 and Chapter 7 for more detail.)

Note: Depending on the type(s) of equipment to be installed, energy performance credits associated with equipment efficiencies which are above the mandatory minimum values may be dependent on when the permit application is submitted. After the implementation date of these Standards (October 1, 2005), the Federal appliance standards will mandate increases in the efficiency of certain types of equipment according to the dates listed in the Appliance Efficiency Regulations.

4.2 Equipment Requirements

All of the equipment requirements are mandatory measures. There are no prescriptive requirements or acceptance requirements.

The mandatory requirements for mechanical equipment must be included in the system design whether compliance is shown by the prescriptive or the performance approach. These features have been shown to be cost effective over a wide range of building types and mechanical systems.

It is worth noting that most mandatory features for equipment efficiency are requirements for the manufacturer. It is the responsibility of the designer, however, to specify products in the building design that meet these requirements.

Mechanical equipment subject to the mandatory requirements must:

- Be certified by the manufacturer as complying with the efficiency requirements as prescribed in:
  - §111 Appliances regulated by the Appliance Efficiency Regulations;
  - §112 Space Conditioning;
  - §113 Service Water Heating Systems and Equipment;
  - §114 Pool and Spa Heating Systems and Equipment;
  - §115 Pilot Lights Prohibited
- Be specified and installed in accordance with:
  - §112 Requirements for Controls
  - §113 Installation Requirements

- §121 Requirements for Ventilation;
- §122 Required Controls for Space Conditioning Systems;
- §123 Requirements for Pipe Insulation;
- §124 Requirements for Ducts and Plenums.

4.2.1 Equipment Certification

§111-113

Mechanical equipment installed in a building subject to these regulations must be certified as meeting certain minimum efficiency and control requirements. These requirements are contained in §112 or §113. The AFUE, COP, EER, IPLV, combustion efficiency, and thermal efficiency values of all equipment must be determined using the applicable test method specified in the Standards.

1. Where more than one efficiency standard or test method is listed, the requirements of both shall apply. For example, water-cooled air conditioners have an EER requirement for full load operation and an IPLV for part load operation. The air conditioner must have both a rated EER and IPLV equal to or higher than that specified in the standard at the specified Air-Conditioning and Refrigeration Institute (ARI) standard rating conditions [§112(a)1 & 2 and §113(b)1 & 2].

2. Where equipment can serve more than one function, such as both heating and cooling, or space heating and water heating, it must comply with the requirements applicable to each function.

3. Where a requirement is for equipment rated at its “maximum rated capacity” or “minimum rated capacity,” the capacity shall be as provided for and allowed by the controls during steady state operation. For example, a boiler with high/low firing must meet the efficiency requirements when operating at both its maximum capacity and minimum capacity [Section 112(a)4 and §113(b)4].

4. Manufacturers of central air conditioners and heat pumps, room A/C, package terminal A/C, package terminal heat pumps, spot air conditioners, computer room air conditioners, central fan-type furnaces, gas space heaters, boilers, pool heaters and water heaters are regulated through the Title 20 Appliance Efficiency Regulations. Manufacturers must certify to the Energy Commission that their equipment meets or exceeds minimum standards.

5. Electric water-cooled centrifugal chillers that are not designed for operation at the ARI Standard 550/590-1998 test conditions of 44°F chilled water supply and 85°F condenser water supply and design condenser flow of 3 gpm/ton must comply with the modified efficiency levels in the Standards Tables 112-H, 112-I, and 112-J in the Standards for full-load operation and Standards Tables 112-K, 112-L, and 112-M for part-load operation. Many water-cooled centrifugal chillers designed for the moderate climates of California cannot operate stably at the ARI test conditions. For those cases the manufacturers shall provide ARI certified performance data at these adjusted conditions upon request.

Equipment not covered by the Appliance Efficiency Regulations is regulated by §112 and §113 of the Standards. To comply, equipment specified in the plans and specifications must meet the minimum standards mandated in that section. Manufacturers of equipment not regulated by the Appliance Efficiency Regulations are not required to certify their equipment to the Energy Commission; it is the responsibility of the designer and contractor to specify and install equipment that complies.

To verify certification, use one of the following options:

- The Energy Commission's website includes listings of energy efficient appliances for several appliance types. The website address is http://www.energy.ca.gov/efficiency/appliances. The Energy Commission's Hotline staff can provide further assistance [1-800-772-3300 or (916) 654-5106] if not found on the website.
- The complete appliance database can be downloaded. This requires spreadsheet programs compatible with Microsoft EXCEL. To use the data, a user must download the database file (or files), download a brand file and a manufacturer file and then decompress the files. Next, the user will need to download a description file that provides details on what is contained in each of the data fields. With these files, and using database software, the data can be sorted and manipulated.
- The Air Conditioning and Refrigeration Institute (ARI) Directory of Certified Unitary Products and Directory of Certified Applied Air-Conditioning Products can be used to verify certification of air-conditioning equipment.
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4.2.2 Furnace Standby Loss Controls

§112c

Forced air gas- and oil-fired furnaces with input ratings ≥225,000 Btu/h are required to have controls and designs that limit their standby losses:

- They must have either an intermittent ignition or interrupted device (IID). Standing pilot lights are not allowed.
- They must have either power venting or a flue damper. A vent damper is an acceptable alternative to a flue damper for furnaces where combustion air is drawn from the conditioned space.

Any furnace with an input rating ≥225,000 Btu/h that is not located within the conditioned space must have jacket losses not exceeding 0.75% of the input rating. This includes electric furnaces as well as fuel-fired units.

4.2.3 Pilot Lights

§115

Pilot lights are prohibited in:

- Pool and spa heaters [§114(a)5].
- Household cooking appliances unless the appliance does not have an electrical connection, and the pilot consumes less than 150 Btu/h [§115(b)].
- Fan type central furnaces. This includes all space-conditioning equipment that distributes gas-heated air through duct work [§115(a)]. This prohibition does not apply to radiant heaters, unit heaters, boilers or other equipment that does not use a fan to distribute heated air.

Example 4-1

Question

If a gas-pack with 15 tons cooling and 260,000 Btu/h maximum heating capacity has an EER = 9.6 and a heating efficiency of 78%, does it comply?

Answer

No. The cooling side complies because the EER exceeds the requirements of 9.5 for units without electric heat. The cooling requirements in Standards Table 112-A require an EER of 9.7 for units between 135 KBtuh and 240 KBtuh with electric resistance heat and footnote b reduces this to 9.5 for units with all other heating sections. With gas heat and an EER of 9.6 this unit complies. Note that the 0.2 deduction provided in the efficiency tables 112-A and 112-B compensate for the higher fan power required to move air over the heat exchangers for fuel-fired heaters.

The heating efficiency must be at least 80% thermal efficiency; therefore the unit does not comply.

Example 4-2

Question

A 500,000 Btu/h gas-fired boiler with high/low firing has a full load combustion efficiency of 82%, 78% thermal efficiency and a low-fire combustion efficiency of 80%. Does the unit comply?

Answer

Yes. The combustion efficiency is at least 80% at both, the maximum- and minimum-rated capacity. The thermal efficiency must be greater than 75% as well.

Example 4-3

Question

A 300 ton centrifugal chiller is designed to operate at 44°F chilled water supply, 80°F condenser water supply and 3 gpm/ton condenser water flow, what is the required COP and IPLV?

Answer

As the chiller is centrifugal and is designed to operate at a condition different from ARI Standard 550/590, the appropriate efficiencies can be found in the Standards Tables 112-I (full load) and 112-L (part load). This chiller must have a COP greater than or equal to 5.97 at the design conditions and an IPLV greater than or equal to 6.37 at the design conditions.

Example 4-4

Question

A 300 ton centrifugal chiller is designed to operate at 45°F chilled water supply, 82°F condenser water supply and 94°F condenser water return, what is the required COP and IPLV?

Answer

As the chiller is centrifugal and is designed to operate at a condition different from ARI Standard 550/590, the appropriate efficiencies can be found in the Standards Tables 112-I (full load) and 112-L (part load). The conditions for this chiller are in between values in Standards Tables 112-I (full load) and 112-L (part load). The equation in the footnotes of the table can be used to find the required COP and IPLV as follows:

LIFT=Tcws-Tchws=82°F -45°F =37°F

Condenser DT=Tcwr-Tcws=94°F -82°F =12°F

X=LIFT+Condenser DT=37°F+12°F=49°F

Kadj=6.1507-0.30244*X + 0.0062692*(X^2) - 0.000045595*(X^3)=1.019

COPadj=Kadj*COPstd=1.019*5.55=5.66

IPLVadj=Kadj*IPLVstd=1.019*5.90=6.01

This chiller must have a COP greater than or equal to 5.66 and an IPLV greater than or equal to 6.01 at the design conditions. Note this number could also have been calculated through interpolation from precalculated table values.

Example 4-5

Question

Are all cooling towers required to be certified by CTI?

Answer

No. Per footnote c in Standards Table 112-G field erected cooling towers are not required to be certified. Factory assembled towers must either be CTI certified or have their performance verified in a field test (using ATC 105) by a CTI approved testing agency. Furthermore only base models need to be tested, options in the air-stream like access platforms or sound traps will derate the tower capacity by 90% of the capacity of the base model or the manufacturer's stated performance whichever is less.

Example 4-6

Question

What mandatory minimum efficiency does a low temperature chiller designed for ice-storage need to meet?

Answer

None. The ARI 550/590 standard only applies to conventional cooling; equipment operating between 44°F to 48°F of leaving chilled water supply temperatures. Ice storage systems must operate well below this and cannot be rated by this test standard. This is explicitly addressed in the Exception to §112(a). Note that this equipment may not be used for prescriptive compliance.

4.3 Ventilation Requirements

§121

All of the ventilation requirements are mandatory measures. Some measures require acceptance testing, which is addressed in Section 4.3.12

Within a building, all enclosed spaces that are normally used by humans must be continuously ventilated during occupied hours with outdoor air using either natural or mechanical ventilation [§121(a)1]. The Standards highly recommend that spaces that may have unusual sources of contaminants be designed with enclosures to contain the contaminants, and local exhaust systems to directly vent the contaminants outdoors [§121(a)1].

The designation and treatment of such spaces is subject to the designer's discretion. Spaces needing special consideration may include:

- Commercial and coin-operated dry cleaners.
- Bars and cocktail lounges.
- Smoking lounges and other designated smoking areas.
- Beauty and barbershops.
- Auto repair workshops.
- Print shops, graphic arts studios and other spaces where solvents are used in a process.
- Copy rooms, laser printer rooms or other rooms where it is expected that equipment may generate heavy concentrations of ozone or other contaminants.
- Blueprint machines.

"Spaces normally used by humans" refers to spaces where people can be reasonably expected to remain for an extended period of time. Spaces where occupancy will be brief and intermittent, and that do not have any unusual sources of air contaminants, do not need to be directly ventilated. For example:

- A closet does not need to be ventilated provided it is not normally occupied.
- A storeroom that is only infrequently or briefly occupied does not require ventilation. However, a storeroom that can be expected to be occupied for extended periods for clean-up or inventory must be ventilated, preferably with systems controlled by a local switch so that the ventilation system operates only when the space is occupied.

"Continuously ventilated during occupied hours" implies that the design ventilation must be provided throughout the entire occupied period. This means that VAV systems must provide the code required ventilation over their full range of operating supply airflow. Some means of dynamically controlling the minimum ventilation air must be provided. This requirement is part of the acceptance testing that is described in 4.3.12.

4.3.1 Natural Ventilation

§121(b)1

Natural outdoor ventilation may be provided for spaces where all normally occupied areas of the space are within a specific distance from an operable wall or roof opening through which outdoor air can flow. This distance is 20 ft. for most spaces and 25 ft. for hotel/motel guestrooms and high-rise residential spaces. The sum of the operable open areas must total at least 5% of the floor area of each space that is naturally ventilated. The openings must also be readily accessible to the occupants of the space at all times.

Airflow through the openings must come directly from the outdoors; air may not flow through any intermediate spaces such as other occupied spaces, unconditioned spaces, corridors, or atriums. High windows or operable skylights need to have a control mechanism accessible from the floor.

Example 4-7

Question

What is the window area required to ventilate a 30 ft. x 32 ft. classroom?

Answer

In order for all points to be within 20 ft. of an opening, windows must be distributed and run at least along two of the opposite walls. The area of the openings must be:

(32 ft. x 30 ft.) x 5% = 48 ft²

The actual window area must be at least 96 ft² if only half the window can be open at a time.

Calculations must be based on free area, taking into account framing and bug screens; the actual window area is approximately 100 ft² without bug screens and 110 ft² with bug screens.

Example 4-8

Question

Naturally ventilated classrooms are located on either side of a doubly-loaded corridor and transoms are provided between the classrooms and corridor. Can the corridor be naturally ventilated through the classrooms?

Answer

No. The corridor cannot be naturally ventilated through the classrooms and transom openings. The Standards require that naturally ventilated spaces have direct access to properly sized openings to the outdoors. The corridor would require mechanical ventilation using either supply or exhaust fans.

4.3.2 Mechanical Ventilation

§121(b)2 and (d)

Mechanical outdoor ventilation must be provided for all spaces normally occupied that are not naturally ventilated. The Standards require that a space conditioning system provide outdoor air equal to or exceeding the ventilation rates required for each of the spaces that it serves. At the space, the required ventilation can be provided either directly through supply air or indirectly through transfer of air from the plenum or an adjacent space. The required minimum ventilation airflow at the space can be provided by an equal quantity of supply or transfer air. At the air-handling unit the minimum outside air must be the sum of the ventilation requirements of each of the spaces that it serves. The designer may specify higher outside air ventilation rates based on the owner's preference or specific ventilation needs associated with the space. However, specifying more ventilation air than the minimum allowable ventilation rates increases energy consumption and electrical peak demand and increases the costs of operating the HVAC equipment. Thus the designer should have a compelling reason to specify higher design minimum outside air rates than the calculated minimum outside air requirements in the standards.

In summary:

- Ventilation compliance at the space is satisfied by providing supply and/or transfer air.
- Ventilation compliance at the unit is satisfied by providing, at minimum, the outdoor air that represents the sum of the ventilation requirements at each space that it serves.

For each *space* requiring mechanical ventilation the ventilation rates must be the greater of either:

- The conditioned floor area of the space, multiplied by the applicable minimum ventilation rate from the Standards in Table 121-A. This provides dilution for the building borne contaminants like off gassing of paints and carpets.
- 15 cfm per person, multiplied by the expected number of occupants. For spaces with fixed seating (such as a theater or auditorium) the expected number of occupants is the number of fixed seats. For spaces without fixed seating, the expected number of occupants is assumed to be no less than one-half that determined for egress purposes in the 2001 California Building Code (CBC) in Chapter 10. The Standards specify the minimum outdoor ventilation rate to which the system must be designed. If desired, the designer may, with documentation, elect to provide more ventilation air. For example, the design outdoor ventilation rate may be determined using the procedures described in ASHRAE 62, provided the resulting outdoor air quantities are no less than required by the Standards.

Section 4.3.12 describes mandated acceptance test requirements for ventilation air.

Table 4-1 shows the typical maximum occupant loads for various building uses upon which minimum ventilation calculations are based). This provides dilution for the occupant borne contaminants (or bioeffluents) like body odor and germs.

Table 4-2 summarizes the combination of these two rates for typical spaces.

As previously stated, each space-conditioning system must provide outdoor ventilation air as follows. It should be noted that systems employing demand controlled ventilation as approved by the Energy Commission may provide lower quantities of ventilation air during periods of low occupancy:

- For a space-conditioning system serving a single space, the required system outdoor airflow is equal to the design outdoor ventilation rate of the space.
- For a space-conditioning system serving multiple spaces, the required outdoor air quantity delivered by the space-conditioning system must be not less than the sum of the required outdoor ventilation rate to each space. The Standards do not require that each space actually receive its calculated outdoor air quantity [§121(b)2 Exception.] Instead, the actual supply to any given space may be any combination of recirculated air, outdoor air, or air transferred directly from other spaces, provided:

  The total amount of outdoor air delivered by the space-conditioning system(s) to all spaces is at least as large as the sum of the space design quantities

  Each space always receives a supply airflow, including recirculated air and/or transfer air, no less than the calculated outdoor ventilation rate

  When using transfer air, none of the spaces from which air is transferred has any unusual sources of contaminants

The Standards specify the minimum outdoor ventilation rate to which the system must be designed. If desired, the designer may, with documentation, elect to provide more ventilation air. For example, the design outdoor ventilation rate may be determined using the procedures described in ASHRAE 62, provided the resulting outdoor air quantities are no less than required by the Standards.

Section 4.3.12 describes mandated acceptance test requirements for ventilation air.

Table 4-1 – CBC 2001 Occupant Densities (ft² /person)

Use / Application	Occupant Load Factor	Use / Application	Occupant Load Factor
Aircraft Hangars	500	Courtrooms	40
Auction Room	7	Dormitories	50
Assembly Areas		Dwellings	300
Auditoriums	7	Garage Parking	200
Churches/Chapels	7	Healthcare Facilities	
Lobbies	7	Sleeping Rooms	120
Lodge Rooms	7	Treatment Rooms	240
Reviewing Stands	7	Hotel/Apartments	200
Stadiums	7	Kitchens - Commercial	200
Waiting Areas	3	Library	
Conference Room	15	Reading Rooms	50
Dining Rooms	15	Stack Areas	100
Drinking Rooms	15	Locker Room	50
Exhibit Rooms	15	Malls	(see UBC chpt.4)
Gymnasiums	15	Manufacturing Areas	200
Lounges	15	Mechanical Equipment Rooms	300
Stages	15	Day Care	35
Gaming: Keno, Slot Machine and Live Games Area	11	Offices	100
		School Shops/Vocational Rooms	50
Bowling Alley (assume no occupants for lanes)	5/alley+15ft runway	Skating Rinks	50 Skate Area & 15 on Deck
Children's Home	80	Storage/Stock Rooms	300
Home for Aged	80	Stores – Retail Sales Room	
Classrooms	20	Basements and Ground Floor	30
Congregate Residences	200	Upper Floors	60
(Accommodating 10 or less persons and having an area of 3,000 ft² or less)		Swimming Pools	50 Pool Area & 15 on Deck
		Warehouses	500
		All Others	100

Table 4-2 – Required Minimum Ventilation Rate Per Occupancy

Occupancy / Use		UBC Table No. 10-A		Choose Largest		
		ft^2/Occupant	Number of People per 1000 ft²	Ventilation CEC STD Table 121-A cfm/ft²	UBC Based Ventilation cfm/ft²	Req. Vent cfm/ft² (largest)
1)	Aircraft Hangars	500	2	0.15	0.02	0.15
2)	Auction Rooms	7.0	143	0.15	1.07	1.07
3)	Assembly Areas (Concentrated Use)					
	Auditoriums	7.0	143	0.15	1.07	1.07
	Bowling Alleys	4.0	250	0.15	1.88	1.88
	Churches & Chapels (Religious Worship)	7.0	143	0.15	1.07	1.07
	Dance Floors	7.0	143	0.15	1.07	1.07
	Lobbies	7.0	143	0.15	1.07	1.07
	Lodge Rooms	7.0	143	0.15	1.07	1.07
	Reviewing Stands	7.0	143	0.15	1.07	1.07
	Stadiums	7.0	143	0.15	1.07	1.07
	Theaters - All	7.0	143	0.15	1.07	1.07
	Waiting Areas	3.0	333	0.15	2.50	2.50
4)	Assembly Areas (Nonconcentrated Use)	15.0	67	0.15	0.50	0.50
	Conference & Meeting Rooms (1)	15.0	67	0.15	0.50	0.50
	Dining Rooms/Areas	15.0	67	0.15	0.50	0.50
	Drinking Establishments (2)	15.0	67	0.20	0.50	0.50
	Exhibit/Display Areas	15.0	67	0.15	0.50	0.50
	Gymnasiums/Sports Arenas	15.0	67	0.15	0.50	0.50
	Lounges	15.0	67	0.20	0.50	0.50
	Stages	15.0	67	1.50	0.50	1.50
	Gaming, Keno, Slot Machine and Live Games Areas	11.0	91	0.20	0.68	0.68
5)	Auto Repair Workshops	100.0	10	1.50	0.08	1.50
6)	Barber & Beauty Shops	100.0	10	0.40	0.08	0.40
7)	Children's Homes & Homes for Aged	80.0	13	0.15	0.09	0.15
8)	Classrooms	20.0	50	0.15	0.38	0.38
9)	Courtrooms	40.0	25	0.15	0.19	0.19
10)	Dormitories	50.0	20	0.15	0.15	0.15
11)	Dry Cleaning (Coin-Operated)	100.0	10	0.30	0.08	0.30
12)	Dry Cleaning (Commercial)	100.0	10	0.45	0.08	0.45
13)	Garage, Parking	200.0	5	0.15	0.04	0.15
14)	Healthcare Facilities: Sleeping Rooms	120.0	8	0.15	0.06	0.15
	Treatment Rooms	240.0	4	0.15	0.03	0.15
15)	Hotels and Apartments	200.0	5	0.15	0.04	0.15

Occupancy / Use	UBC Table No. 10-A		Choose Largest		
	ft²/Occupant	Number of People per 1000 ft²	Ventilation CEC STD Table 121-A cfm/ft²	UBC Based Ventilation cfm/ft²	Req. Vent cfm/ft² (largest)
Hotel Function Area (3)	15.0	67	0.15	0.50	0.50
Hotel Lobby	100.0	10	0.15	0.08	0.15
Hotel Guest Rooms (<500 ft²)	200.0	5	Footnote 4	Footnote 4	Footnote 4
Hotel Guest rooms (>=500 ft²)	200.0	5	0.15	0.04	0.15
Highrise Residential	200.0	5	Footnote 5	Footnote 5	Footnote 5
16) Kitchen(s)	200.0	5	0.15	0.04	0.15
17) Library: Reading Rooms	50.0	20	0.15	0.15	0.15
Stack Areas	100.0	10	0.15	0.08	0.15
18) Locker Rooms	50.0	20	0.15	0.15	0.15
19) Manufacturing	200.0	5	0.15	0.04	0.15
20) Mechanical Equipment Room	300.0	3	0.15	0.03	0.15
21) Nurseries for Children - Day Care	50.0	20	0.15	0.15	0.15
22) Offices: Office	100.0	10	0.15	0.08	0.15
Bank/Financial Institution	100.0	10	0.15	0.08	0.15
Medical & Clinical Care	100.0	10	0.15	0.08	0.15
23) Retail Stores (See Stores)					
24) School Shops & Vocational Rooms	50.0	20	0.15	0.15	0.15
25) Skating Rinks: Skate Area	50.0	20	0.15	0.15	0.15
On Deck	15.0	67	0.15	0.50	0.50
26) Stores: Retail Sales, Wholesale Showrooms	30.0	33	0.20	0.25	0.25
Basement and Ground Floor	30.0	33	0.20	0.25	0.25
Upper Floors	60.0	17	0.20	0.13	0.20
Grocery	30.0	33	0.20	0.25	0.25
Malls, Arcades, & Atria	30.0	33	0.20	0.25	0.25
27) Swimming Pools: Pool Area	50.0	20	0.15	0.15	0.15
On Deck	15.0	67	0.15	0.50	0.50
28) Warehouses, Industrial & Commercial Storage/Stockrooms (see 4.2.1 b) 4.24.2.1D)	500.0	2	0.15	0.02	0.15
29) All Others -- Including Unknown	100.0	10	0.15	0.08	0.15
Corridors, Restrooms, & Support Areas	100.0	10	0.15	0.08	0.15

Occupancy / Use	UBC Table No. 10-A		Choose Largest		
	ft^2/Occupant	Number of People per 1000 ft²	Ventilation CEC STD Table 121-A cfm/ft²	UBC Based Ventilation cfm/ft²	Req. Vent cfm/ft² (largest)
Commercial & Industrial Work	100.0	10	0.15	0.08	0.15

Footnotes:	Equations used to find:
1) Convention, Conference, Meeting Rooms 2) Bars, Cocktail & Smoking Lounges, Casinos	1) *Number of People per 1000sf* = $\frac{1000}{\text{Sf/Occupant}}$
3) See Conference Rooms or Dining Rooms 4) Guestrooms less than 500 ft² use 30 cfm/guestroom 5) Highrise Residential See 1994 UBC Section 1203 Ventilation	2) *UBC Based Ventilation cfm/ft²* = $\left(\frac{\frac{\text{Number of People per 1000sf}}{1000}}{2}\right)\times 15$ *cfm*

Example 4-9

Question

Ventilation for a two-room building:

Consider a building with two spaces, each having an area of 1,000 ft^2. One space is used for general administrative functions, and the other is used for classroom training. It is estimated that the office will contain seven people, and the classroom will contain 50 (fixed seating). What are the required outdoor ventilation rates?

Answer

1. For the office area, the design outdoor ventilation air is the larger of:

   7 people x 15 cfm/person = 105 cfm

   or

   1,000 ft² x 0.15 cfm/ft² = 150 cfm

   For this space, the design ventilation rate is 150 cfm.

2. For the classroom, the design outdoor ventilation air is the larger of:

   50 people x 15 cfm/person = 750 cfm

   or

   1,000 ft² x 0.15 cfm/ft² = 150 cfm

   For this space the design ventilation rate is 750 cfm.

Assume the total supply air necessary to satisfy cooling loads is 1000 cfm for the office and 1,500 cfm for the classroom. If each space is served by a separate system, then the required outdoor ventilation rate of each system is 150 cfm and 750 cfm, respectively. This corresponds to a 15% outside air (OA) fraction in the office HVAC unit, and 50% in the classroom unit.

If both spaces are served by a central system, then the total supply will be (1,000 + 1,500) cfm = 2500 cfm. The required outdoor ventilation rate is (150 + 750) = 900 cfm total. The actual outdoor air ventilation rate for each space is:

Office OA = 900 cfm x (1,000 cfm / 2,500 cfm) = 360 cfm

Classroom OA = 900 cfm x (1,500 cfm / 2,500 cfm) = 540 cfm

While this simplistic analysis suggests that the actual OA cfm to the classroom is less than design (540 cfm vs. 750 cfm), the analysis does not take credit for the dilution effect of the air recirculated from the office. The office is over-ventilated (360 cfm vs. 150 cfm) so the concentration of pollutants in the office return air is low enough that it can be used, along with the 540 cfm of outdoor air, to dilute pollutants in the classroom. The Standards allow this design provided that the system always delivers at least 750 cfm to the classroom (including transfer or recirculated air), and that any transfer air is free of unusual contaminants.

4.3.3 Direct Air Transfer

The Standards allow air to be directly transferred from other spaces in order to meet a part of the ventilation supply to a space, provided the total outdoor quantity required by all spaces served by the building's ventilation system is supplied by the mechanical systems. This method can be used for any space, but is particularly applicable to conference rooms, toilet rooms, and other rooms that have high ventilation requirements. Transfer air must be free from any unusual contaminants, and as such should not be taken directly from rooms where such sources of contaminants are anticipated. It is typically taken from the return plenum or directly from an adjacent space.

Air may be transferred using any method that ensures a positive airflow. Examples include dedicated transfer fans, exhaust fans and fan-powered VAV boxes. A system having a ducted return may be balanced so that air naturally transfers into the space. Exhaust fans serving the space may discharge directly outdoors, or into a return plenum. Transfer systems should be designed to minimize recirculation of transfer air back into the space; duct work should be arranged to separate the transfer air intake and return points.

When each space in a two-space building is served by a separate constant volume system, the calculation and application of ventilation rate is straightforward, and each space will always receive its design outdoor air quantity. However, a central system serving both spaces does not deliver the design outdoor air quantity to each space. Instead, one space receives more than its allotted share, and the other less. This is because the training room has a higher design outdoor ventilation rate and/or a lower cooling load relative to the other space.

4.3.4 Distribution of Outdoor Air to Zonal Units

§121(d)

When a return plenum is used to distribute outside air to a zonal heating or cooling unit, the outside air supply must be connected either:

1. Within five ft. of the unit; or

2. Within 15 ft. of the unit, with the air directed substantially toward the unit, and with a discharge velocity of at least 500 ft. per minute.

Water source heat pumps and fan coils are the most common application of this configuration. The unit fans should be controlled to run continuously during occupancy in order for the ventilation air to be circulated to the occupied space.

A central space-conditioning system(s) augmented by a few zonal units for spot conditioning may use transfer air from spaces served by the central system. A direct source of outdoor air is not required for each zonal unit. Similarly, transfer air may be used in buildings having central interior space-conditioning systems with outdoor air, and zonal units on the perimeter (without outdoor air).

While not required, the Standards recommend that sources of unusual contaminants be controlled through the use of containment systems that capture the contaminants and discharge them directly outdoors. Such systems may include exhaust hoods, fume hoods, small space exhausts and differential pressure control between spaces. The designer is advised to consult ASHRAE standards or other publications for guidance in this subject.

4.3.5 Ventilation System Operation and Controls

§121(c) & §121(f)

Outdoor Ventilation Air and VAV Systems

Except for systems employing Energy Commission-certified demand controlled ventilation (DCV) devices, the Standards require that the minimum rate of outdoor air calculated per §121(b)2 be provided to each space *at all times* when the space is normally occupied [§121(c)1]. For spaces served by variable air volume (VAV) systems, this means that the minimum supply setting of each VAV box should be no less than the design outdoor ventilation rate calculated for the space, unless transfer air is used. If transfer air is used, the minimum box position, plus the transfer air, must meet the minimum ventilation rate. If transfer air is not used, the box must be controlled so that the minimum required airflow is maintained at all times (unless demand controlled ventilation is employed).

The design outdoor ventilation rate at the system level must always be maintained when the space is occupied, even when the fan has modulated to its minimum capacity [§121(c)1]. Section 4.3.12 describes mandated acceptance test requirements for outside air ventilation in VAV air handling systems. In these tests, the minimum outside air in VAV systems will be measured both at full flow and with all boxes at minimum position.

Figure 4-2 shows a typical VAV system. In standard practice, the testing and balancing (TAB) contractor sets the minimum position setting for the outdoor air damper during construction. It is set under the conditions of design airflow for the system, and remains in the same position throughout the full range of system operation. Does this meet code? The answer is no. As the system airflow drops so will the pressure in the mixed air plenum. A fixed position on the minimum outdoor air damper will produce a varying outdoor airflow. As depicted in Figure 4-2, this effect will be approximately linear (in other words outdoor air airflow will drop directly in proportion to the supply airflow).

The following paragraphs present several methods used to dynamically control the minimum outdoor air in VAV systems, which are described in detail below.

Regardless of how the minimum ventilation is controlled, care should be taken to reduce the amount of outdoor air provided when the system is operating during the weekend or after hours with only a fraction of the zones active. §122(g) requires provision of "isolation zones" of 25,000 ft^2 or less. This can be provided by having the VAV boxes return to fully closed when their associated zone is in unoccupied mode. When a space or group of spaces is returned to occupied mode (e.g. through off-hour scheduling or a janitor's override) only the boxes serving those zones need to be active. During this partial occupancy the ventilation air can be reduced to the requirements of those zones that are active. If all zones are of the same occupancy type (e.g. private offices), simply assign a floor area to each isolation zone and prorate the minimum ventilation area by the ratio of the sum of the floor areas presently active divided by the sum of all the floor areas served by the HVAC system.

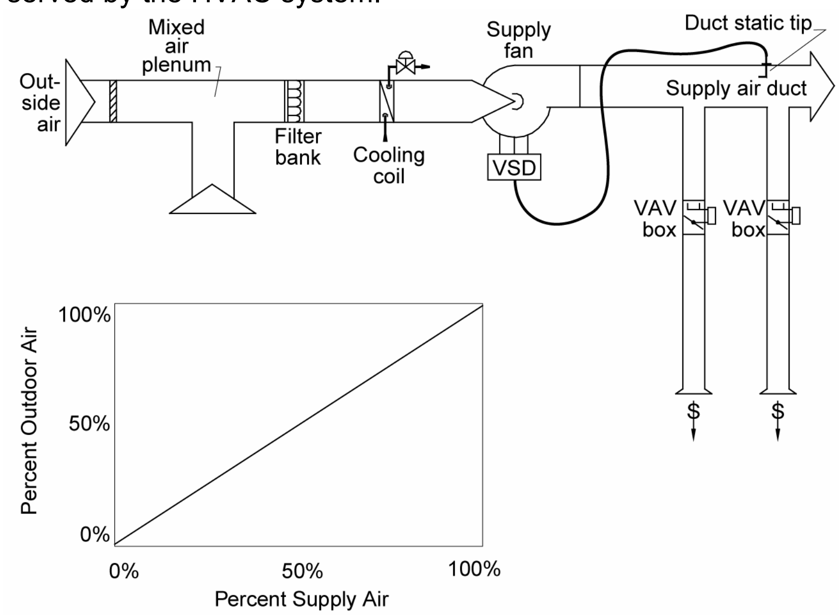


Figure 4-2 – VAV Reheat System with a Fixed Minimum outdoor Air Damper Setpoint

Fixed Minimum Damper Setpoint

This method does not comply with Title 24; the airflow at a fixed minimum damper position will vary with the pressure in the mixed air plenum (see Figure 1-2).

Dual Minimum Setpoint Design

This method complies with Title 24 requirements. An inexpensive enhancement to the fixed damper setpoint design is the dual minimum setpoint design, commonly used on some packaged AC units. The minimum damper position is set proportionally based on fan speed or airflow between a setpoint determined when the fan is at full speed (or airflow) and minimum speed (or airflow). This method complies with the letter of Title 24 but is not accurate over the entire range of airflow rates and when there are wind or stack effect pressure fluctuations. But with DDC, this design has very low costs.

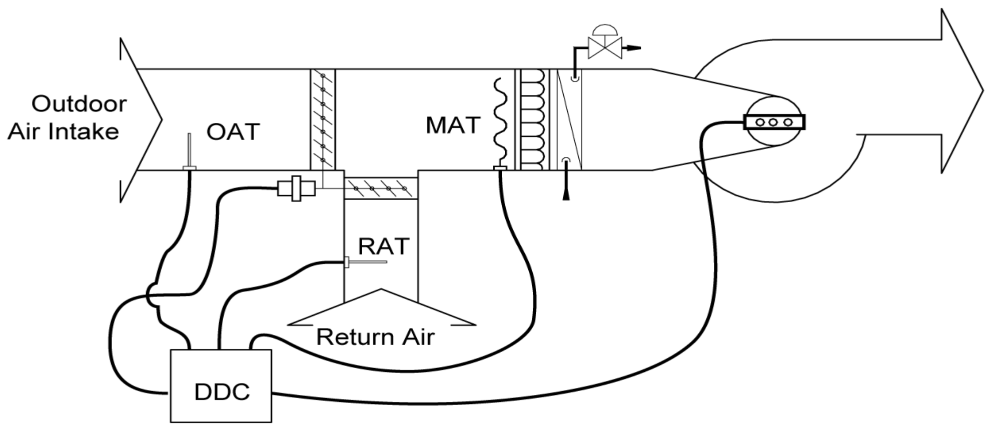
Energy Balance Method

This method complies with Title 24 requirements; however, compliance may be difficult for reasons discussed below. The energy balance method (Figure 4-3) uses temperature sensors in the outside, as well as return and mixed air plenums to determine the percentage of outdoor air in the supply air stream. The outdoor airflow is then calculated using the equations shown in Figure 4-3. This method requires an airflow monitoring station on the supply fan.

This approach does not generally work for several reasons:

- The accuracy of the mixed air temperature sensor is critical to the calculation but is very difficult to perform with any precision in real applications. Even with an averaging type bulb, most mixing plenums have some stratification or horizontal separation between the outside and mixed airstreams.[7]
- Even with the best installation, high accuracy sensors, and field calibration of the sensors, the equation for percent outdoor air will become inaccurate as the return air temperature approaches the outdoor air temperature. When they are equal, this equation predicts an infinite percentage outdoor air.
- The accuracy of the airflow monitoring station at low supply airflows is likely to be low.
- The denominator of the calculation amplifies sensor inaccuracy as the return air temperature approaches the outdoor air temperature.

[7] This was the subject of ASHRAE Research Project 1045-RP, “Verifying Mixed Air Damper Temperature and Air Mixing Characteristics.” Unless the return is over the outdoor air there are significant problems with stratification or airstream separation in mixing plenums.



%OA = (MAT - RAT) / (OAT - RAT)
CFM - OA = %OA * CFM - SA

Figure 4-3 – Energy Balance Method of Controlling Minimum Outdoor Air

Return Fan Tracking

This method complies with Title 24 requirements; however, this approach is not accurate because the cumulative error of the two airflow measurements can be large, particularly at low supply/return airflow rates. It only works theoretically when the minimum outdoor air rate equals the rate of air required to maintain building pressurization (the difference between supply air and return air rates). Return fan tracking (Figure 4-4) uses airflow monitoring stations on both the supply and return fans. The theory behind this is that the difference between the supply and return fans has to be made up by outdoor air, and controlling the flow of return air forces more ventilation into the building. Several problems occur with this method: 1) the relative accuracy of airflow monitoring stations is poor, particularly at low airflows; 2) the cost of airflow monitoring stations; 3) it will cause building pressurization problems unless the ventilation air is equal to the desired building exfiltration plus the building exhaust. ASHRAE research has also demonstrated that in some cases this arrangement can cause outdoor air to be drawn into the system through the exhaust dampers due to negative pressures at the return fan discharge.

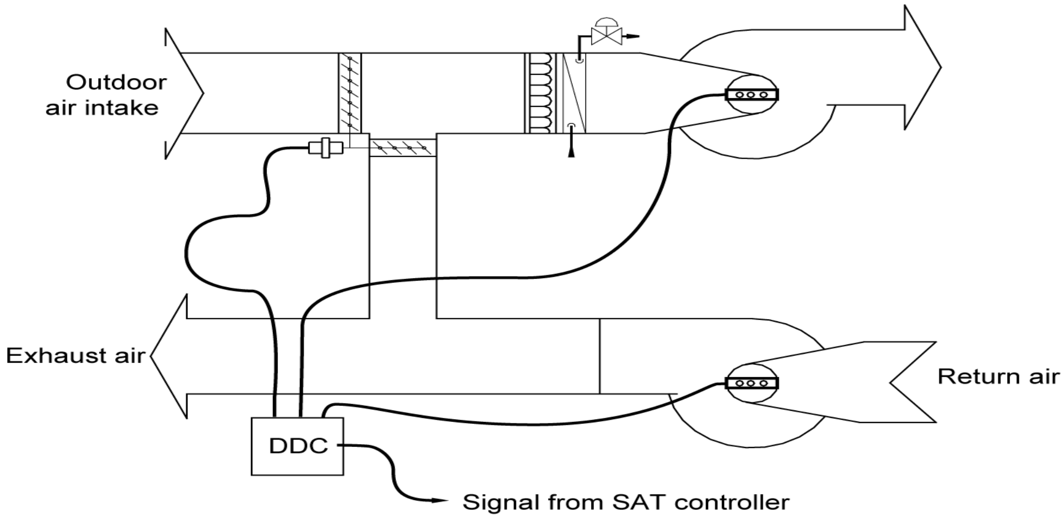


Figure 4-4 – Return Fan Tracking

Airflow Measurement of the Entire Outdoor Air Inlet

This method complies with Title 24 requirements; however, it may or may not work depending on the airflow measurement technology. Most airflow sensors will not be accurate to a 5-15% turndown (the normal commercial ventilation range. Controlling the outdoor air damper by direct measurement with an airflow monitoring station (Figure 4-5) can be an unreliable method. Its success relies on the turndown accuracy of the airflow monitoring station. Depending on the loads in a building, the ventilation airflow can be between 5 and 15% of the design airflow. If the outdoor airflow sensor is sized for the design flow for the airside economizer, this method has to have an airflow monitoring station that can turn down to the minimum ventilation flow (between 5 and 15%). Of the different types available, only a hot-wire anemometer array is likely to have this low-flow accuracy while traditional pitot arrays will not. One advantage of this approach is that it provides outdoor airflow readings under all operating conditions, not just when on minimum outdoor air. For highest accuracy, provide a damper and outdoor air sensor for the minimum ventilation air that is separate from the economizer outdoor air intake.

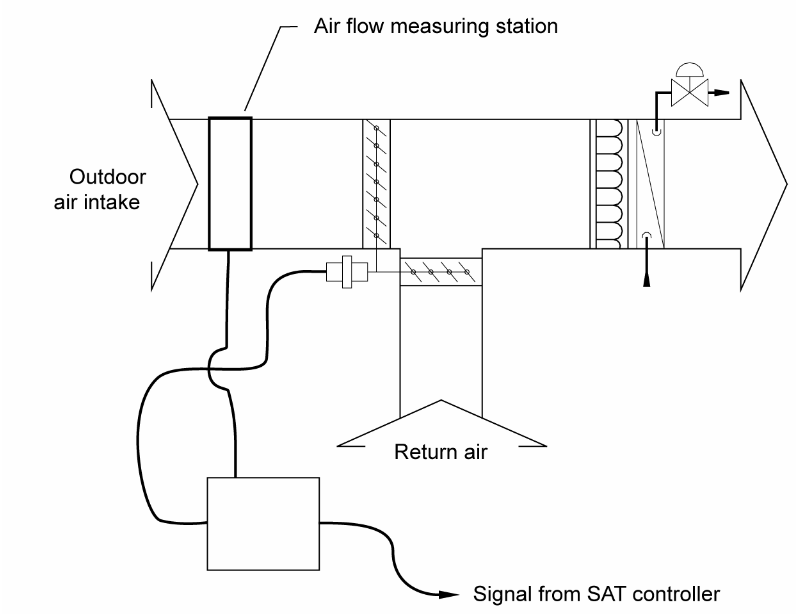


Figure 4-5 – Airflow Measurement of 100% Outdoor Air

Injection Fan Method

This method complies with Title 24 requirements, but it is expensive and may require additional space. Note that an airflow sensor and damper are required since fan airflow rate will vary as mixed air plenum pressure varies. The injection fan method (Figure 4-6) uses a separate outdoor air inlet and fan sized for the minimum ventilation airflow. This inlet contains an airflow monitoring station, and a fan with capacity control (e.g., discharge damper; VFD), which is modulated as required to achieve the desired ventilation rate. The discharge damper is recommended since a damper must be provided anyway to shut off the intake when the AHU is off, and also to prevent excess outdoor air intake when the mixed air plenum is very negative under peak conditions. (The fan is operating against a negative differential pressure and thus cannot stop flow just by slowing or stopping the fan.) This method works, but the cost is high and often requires additional space for the injection fan assembly.

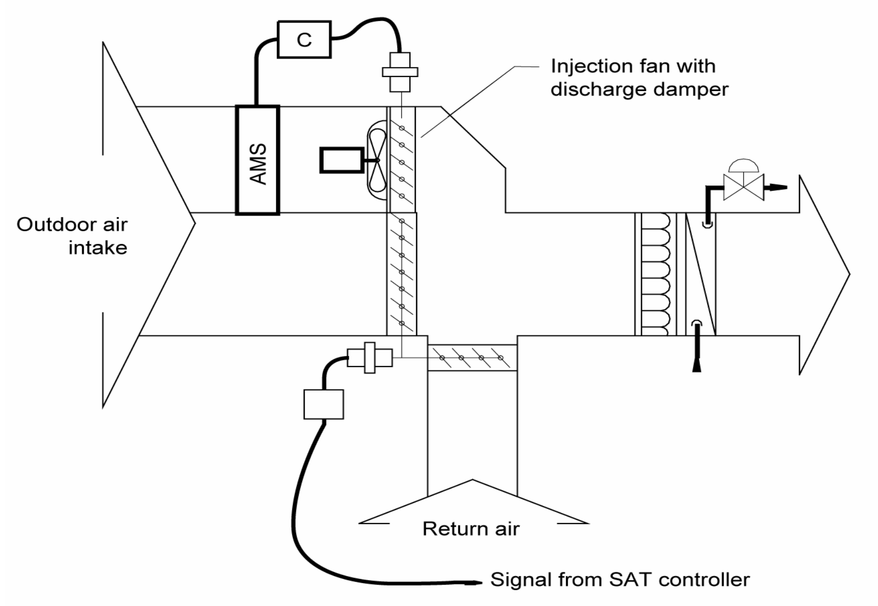


Figure 4-6 – Injection Fan with Dedicated Minimum Outdoor Air Damper

Dedicated Minimum Ventilation Damper with Pressure Control

This approach is low cost and takes little space. It can be accurate if the differential setpoint corresponding to the minimum outdoor air rate is properly set in the field. An inexpensive but effective design uses a minimum ventilation damper with differential pressure control (Figure 4-7). In this method, the economizer damper is broken into two pieces: a small two position damper controlled for minimum ventilation air and a larger, modulating, maximum outdoor air damper that is used in economizer mode. A differential pressure transducer is placed across the minimum outdoor air damper. During start-up, the air balancer opens the minimum outside air (OA) damper and return air damper, closes the economizer OA damper, runs the supply fan at design airflow, measures the OA airflow (using a hand-held velometer) and adjusts the minimum OA damper position until the OA airflow equals the design minimum OA airflow. The linkages on the minimum OA damper are then adjusted so that the current position is the “full open” actuator position. At this point the design pressure (DP) across the minimum OA damper is measured. This value becomes the DP setpoint. The principle used here is that airflow is constant across a fixed orifice (the open damper) at fixed DP.

As the supply fan modulates when the economizer is off, the return air damper is controlled to maintain the DP setpoint across the minimum ventilation damper.

The main downside to this method is the complexity of controls and the potential problems determining the DP setpoint in the field. It is often difficult to measure the outdoor air rate due to turbulence and space constraints.

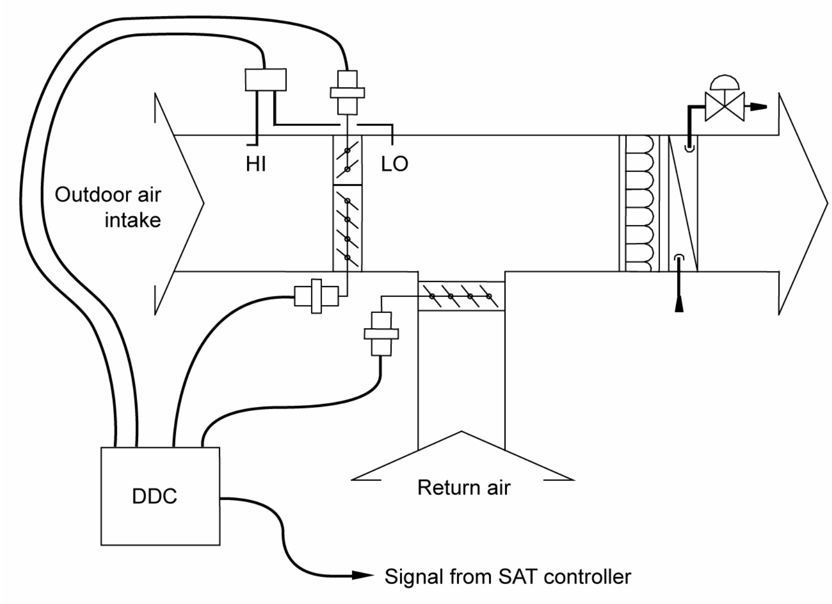


Figure 4-7 – Minimum Outdoor Air Damper with Pressure Control

Example 4-10

Question

Minimum VAV cfm:

If the minimum required ventilation rate for a space is 150 cfm, what is the minimum allowed airflow for its VAV box when the design percentage of outdoor air in the supply is 20%?

Answer

The minimum allowed airflow may be as low as 150 cfm provided that enough outdoor air is supplied to all spaces combined to meet the requirements of §121(b)2 for each space individually.

4.3.6 Pre-Occupancy Purge

§121(c)2

Since many indoor air pollutants are out gassed from the building materials and furnishings, the Standards require that buildings having a scheduled operation be purged before occupancy [§121(c)2]. Immediately prior to occupancy, outdoor ventilation must be provided in an amount equal to the lesser of:

- The minimum required ventilation rate for one hour; or
- Three complete air changes.

Either criteria can be used to comply with the Standards. Three complete air changes means an amount of ventilation air equal to three times the volume of the occupied space. This air may be introduced at any rate provided for and allowed by the system, so that the actual purge period may be less than an hour.

A pre-occupancy purge is not required for buildings or spaces that are not occupied on a scheduled basis, such as storage rooms. Also, a purge is not required for spaces provided with natural ventilation.

Where pre-occupancy purge is required, it does not have to be coincident with morning warm-up (or cool-down). The simplest means to integrate the two controls is to simply schedule the system to be occupied one hour prior to the actual time of anticipated occupancy. This allows the optimal start, warm-up or pull-down routines to bring the spaces up to (or down to) desired temperatures before opening the outdoor air damper for ventilation. This will reduce the required system heating capacity and ensure that the spaces will be at the desired temperatures and fully purged at the start of occupancy.

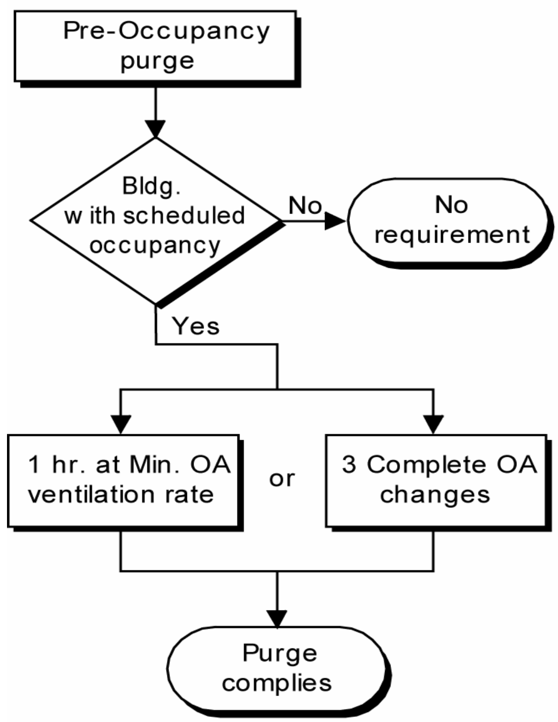


Figure 4-8 – Pre-Occupancy Purge Flowchart

Example 4-11

Question

Purge Period:

What is the length of time required to purge a space 10 ft. high with an outdoor ventilation rate of 1.5 cfm/ft²?

Answer

For three air changes, each ft^2 of space must be provided with:

OA volume = 3 x 10 = 30 cf/ft^2

At a rate of 1.5 cfm/ft², the time required is:

Time = 30 cf/ft^2 / 1.5 cfm/ft² = 20 minutes

Example 4-12

Question

Purge with Natural Ventilation:

In a building with natural ventilation, do the windows need to be left open all night to accomplish a building purge?

Answer

No. A building purge is required only for buildings with mechanical ventilation systems.

Example 4-13

Question

Purge with Occupancy Timer:

How is a purge accomplished in a building without a regularly scheduled occupancy whose system operation is controlled by an occupancy sensor?

Answer

There is no purge requirement for this building. Note that occupancy sensors and manual timers can only be used to control ventilation systems in buildings that are intermittently occupied without a predictable schedule.

4.3.7 Demand Controlled Ventilation

§121(c)

Demand controlled ventilation (DCV) systems reduce the amount of ventilation supply air in response to a measured level of carbon dioxide (CO_2) in the breathing zone. The Standards only permit CO_2 sensors for the purpose of meeting this requirement; VOC and so-called "IAQ" sensors are not approved as alternative devices to meet this requirement. The Standards only permit DCV systems to vary the ventilation component that corresponds to occupant bioeffluents (this is basis for the 15 cfm/person portion of the ventilation requirement). Since only CO_2 sensors directly track occupancy they are the only sensors permitted.

The Standards requires the use of DVC systems for spaces with all of the following characteristics:

- Served by single zone units.
- Have a design occupancy of 40 ft^2/person or smaller (for areas without fixed seating where the design density for egress purposes in the CBC is 40 ft^2/person or smaller).
- Has an outdoor air economizer.

There are three exceptions to this requirement:

1. Classrooms (they are permitted to use DCV but not required to)

2. Where the space exhaust is greater than the Standards Table 121(b) value minus 0.2 cfm/ft^2.

3. Spaces that have processes or operations that generate dusts, fumes, mists, vapors, or gases and are not provided with local exhaust ventilation (such as indoor operation of internal combustion engines or areas designated for unvented food service preparation).

Classrooms were exempted due to concerns about equipment maintenance in school buildings. The second exception relates to the fact that spaces with high exhaust requirements won't have any room to turn down (therefore there will be minimal savings from the DCV controls). The third exception recognizes that some spaces may need additional ventilation due to contaminants that are not occupant borne. It addresses spaces like theater stages where theatrical fog may be used or movie theater lobbies where unvented popcorn machines may be emitting odors and vapors into the space in either case justifying the need for higher ventilation rates.

Although not required, the Standards permit design professionals to apply DCV on any intermittently occupied spaces served by either single-zone or multiple-zone equipment.

CO_2 based DCV is based on two principles:

1. Several studies (Berg-Munch et al. 1986, Cain et al. 1983, Fanger 1983 and 1988, Iwashita et al. 1990, Rasmussen et al. 1985) concluded that about 15 cfm of outdoor air ventilation per person will control human body odor such that roughly 80% of unadapted persons (visitors) will find the odor to be at an acceptable level. These studies are the basis of the 15 cfm/person rate required by these Standards and most building codes. This ventilation rate can be roughly equated to CO_2 concentration using the following steady-state equation.

$$V = \frac{\dot{N}}{\left(C_{in,ss} - C_{out}\right)}$$

where V is the ventilation rate per person, $\dot{N}$ is the CO_2 generation rate per person, $C_{in,ss}$ is the steady-state value of the indoor CO_2 concentration, and C_{out} is the outdoor concentration. At the rate of CO_2 generated by adults at typical activity levels in offices, 15 cfm/person equates to a differential CO_2 concentration (indoor minus outdoor) of approximately 700 ppm.

2. The same level of odor acceptability was found to occur at 700 ppm differential CO_2 concentration even for spaces that were not at equilibrium (Berg-Munch et al. 1986, Fanger 1983, Rasmussen et al. 1985), and the correlation was not strongly dependent on the level of physical activity. This suggests that while CO_2 concentration may not track the number of occupants when spaces are not at steady-state, it does track the concentration of bioeffluents that determine people's perception of air quality. It also suggests that odorous bioeffluents are generated at approximately the same rate as CO_2.

Hence as activity level and bioeffluent generation rate increases ($\dot{N}$ in the equation above), the rate of outdoor air required to provide acceptable air quality (V) increases proportionally, resulting in the same differential CO_2 concentration.

Note that CO_2 concentration only tracks indoor contaminants that are generated by occupants themselves and, to a lesser extent, their activities. It will not track other pollutants, particularly volatile organic compounds (VOCs) that off-gas from furnishings and building materials. Hence, where permitted or required by the Standards, demand controlled ventilation systems cannot reduce the outdoor air ventilation rate below the floor rate listed in Standards Table 121-A (typically 0.15 cfm/ft^2) during normally occupied times.

DCV systems save energy if the occupancy varies significantly over time. Hence they are most cost effective when applied to densely occupied spaces like auditoriums, conference rooms, lounges or theaters. Because DCV systems must maintain the floor ventilation rate listed in Standards Table 121-A, they will not be applicable to sparsely occupied buildings such as offices where the floor rate always exceeds the minimum rate required by the occupants (see Table 4-2).

Where DCV is employed (whether mandated or not) the controls must meet all of the following requirements:

- Sensors must be provided in each room served by the system that has a design occupancy of 40 ft^2/person or less.
- The CO_2 sensors must be located in the breathing zone (between 1 and 6 ft. above the floor). Sensors in return air ducts are not allowed since they can result in under-ventilation due to CO_2 measurement error caused by short-circuiting of supply air into return grilles and leakage of outdoor air (or return air from other spaces) into return air ducts.
- The ventilation must be maintained that will result in a concentration of CO_2 at or below 600 ppm above the ambient level. The ambient levels can either be assumed to be 400 ppm or dynamically measured. At 400 ppm outside CO_2 concentration, the resulting DCV CO_2 setpoint would be 1000 ppm. (Note that a 600 ppm differential is less than the 700 ppm that corresponds to the 15 cfm/person ventilation rate. This provides a margin of safety against sensor error, and because 1000 ppm CO_2 is a commonly recognized guideline value and referenced in earlier versions of ASHRAE Standard 62.)
- Regardless of the CO_2 sensor's reading, the system is not required to provide more than the minimum ventilation rate required by §121(b). This high limit can be implemented in the controls.
- The system shall always provide a minimum ventilation of the sum of the Standards Table 121-A values for all rooms with DCV and §121(b)2 (Table 4-2 of this manual) for all other spaces served by the system. This is a low limit setting that must be implemented in the controls.
- The CO_2 sensors must be factory certified to have an accuracy of no less than 75 ppm over a five-year period without recalibration in the field. A number of manufacturers have "self calibrating" sensors now that adjust to ambient levels during unoccupied times. The manufacturers of sensors must provide a document to installers that their sensors meet these requirements. The installer must make this certification information available to the builder, building inspectors and, if specific sensors are specified on the plans, to plan checkers.

Section 4.3.12 describes mandated acceptance test requirements for DCV systems.

Example 4-14

Question

Does a single zone air-handling unit serving a 2,000 ft² auditorium with fixed seating for 240 people require demand controlled ventilation?

Answer

Yes if it has an air-side economizer. There are three tests for the requirement.

The first test is whether the design occupancy is 40 ft²/person or less. This space has 2,000 ft²/240 people or 8.3 ft² /person.

The second test is that the unit is single zone

The third is that it has an air-side economizer.

A single CO_2 sensor could be used for this space provided it is certified by the manufacturer to cover 2,000 ft² of space. The sensor must be placed directly in the space.

Example 4-15

Question

If two separate units are used to condition the auditorium in the previous example, is demand controlled ventilation required?

Answer

Yes, if they each meet the three tests.

4.3.8 Fan Cycling

While §121(c)1 requires that ventilation be continuous during normally occupied hours, Exception No. 2 allows the ventilation to be disrupted for not more than five minutes out of every hour. In this case the ventilation rate during the time the system is ventilating must be increased so the average rate over the hour is equal to the required rate.

This restriction limits the duty cycling of fans by energy management systems to not more than five minutes out of every sixty minutes. In addition, when a space-conditioning system that also provides ventilation is controlled by a thermostat incorporating a fan “On/Auto” switch, the switch should be set to the “On” position. Otherwise, during mild conditions, the fan may be off the majority of the time.

4.3.9 Variable Air Volume (VAV) Changeover Systems

Some VAV systems provide conditioned supply air, either heated or cooled, through a single set of ducting. These systems are called VAV changeover systems or, perhaps more commonly, variable volume and temperature (VVT™) systems, named after a control system distributed by Carrier Corp. In the event that heating is needed in some spaces at the same time that cooling is needed in others, the system must alternate between supplying heated and cooled air. When the supply air is heated, for example, the spaces requiring cooling are isolated (cut off) by the VAV dampers and must wait until the system switches back to cooling mode. In the meantime, they are generally not supplied with ventilation air.

Systems of this type may not meet the ventilation requirements if improperly applied. Where changeover systems span multiple orientations the designer must make control provisions to ensure that no zone is shut off for more than five minutes per hour and that ventilation rates are increased during the remaining time to compensate. Alternatively, minimum damper position or airflow setpoints can be set for each zone to maintain supply air rates, but this can result in temperature control problems since warm air will be supplied to spaces that require cooling, and vice versa. Changeover systems that are applied to a common building orientation (e.g., all east or all interior) are generally the most successful since zones will usually have similar loads, allowing minimum airflow rates to be maintained without causing temperature control problems.

4.3.10 Adjustment of Ventilation Rate

Section 121(b) specifies the minimum required outdoor ventilation rate, but does not restrict the maximum. However, if the designer elects to have the space-conditioning system operate at a ventilation rate higher than the rate required by the Standards, then the Standards require that the space-conditioning system must be adjustable so that in the future the ventilation rate can be reduced to the amount required by the Standards or the rate required for make-up of exhaust systems that are required for a process, for control of odors, or for the removal of contaminants within the space [§121(e)].

In other words, a system can be designed to supply higher than minimum outside air volumes provided dampers or fan speed can be adjusted to allow no more than the minimum volume if, at a later time, someone decides it is desirable. The Standards preclude a system designed for 100% outdoor air, with no provision for any return air, unless the supply air quantity can be adjusted to be equal to the designed minimum outdoor air volume. The intent is to prevent systems from being designed that will permanently over-ventilate spaces.

4.3.11 Miscellaneous Dampers

§122(f)

Dampers should not be installed on combustion air intakes, or where prohibited by other provisions of law [§122(f) Exception Nos. 3 & 4]. If the designer elects to install dampers on shaft vents to help control stack-induced infiltration, the damper should be motorized and controlled to open in accordance with applicable fire codes.

4.3.12 Acceptance Requirements

§121(f), 122(h) and 121(c)5

The Standards have acceptance test requirements for:

- Ventilation quantities at design airflow [§121(f)].
- Ventilation quantities at minimum airflow [VAV systems, §121(f)].
- Ventilation system time controls [§122(h)].
- Demand controlled ventilation systems [§121(c)5].

These test requirements are described in Chapter 8 and in the Non-Residential ACM Manual Appendix NJ. They are described in brief in the following paragraphs.

Example 4-16

Question

Maintenance of Ventilation System:

In addition to these commissioning requirements for the ventilation system, are there any periodic requirements for inspection?

Answer

The Standards do not contain any such requirements since they apply to the design and commissioning of buildings, not to its later operation. However, Section 5142 of the General Industry Safety Orders, Title 8, California Safety Code (1987): Mechanically Driven Heating, Ventilating and Air Conditioning (HVAC) Systems to Provide Minimum Building Ventilation, states the following:

(b) Operation and Maintenance

(1) The HVAC system shall be inspected at least annually, and problems found during these inspections shall be corrected within a reasonable time.

(2) Inspections and maintenance of the HVAC systems shall be documented in writing. The employer shall record the name of the individual(s) inspecting and/or maintaining the system, the date of the inspection and/or maintenance, and the specific findings and actions taken. The employer shall ensure that such records are retained for at least five years.

(3) The employer shall make all records required by this section available for examination and copying, within 48 hours of a request, to any authorized representative of the Division (as defined in Section 3207 of Title 8), to any employee of the employer affected by this section, and to any designated representative of said employee of the employer affected by this Section.

Ventilation Airflow

§121(f)

Ventilation airflow has to be certified as within 10% of the design airflow quantities at two points of operation: full design supply airflow and (for VAV systems) at airflow with all VAV boxes at minimum position.

If airflow monitoring stations are provided, they can be used for these measurements.

Ventilation System Time Controls and Preoccupancy Purge

122(h)

Programming for preoccupancy purge and HVAC schedules are checked and certified as part of the acceptance requirements. The sequences are also required to be identified by specification section paragraph number (or drawing sheet number) in the compliance forms.

Demand Controlled Ventilation System

121(c)5

Demand controlled ventilation systems are checked for compliance with sensor location, calibration (either factory certificate or field validation) and tested for system response with both a high signal (from test gas or breathing on the sensor) and low signal (by increasing the setpoint above the ambient level). A certificate of acceptance must be provided to the building department that the demand control ventilation system meets the Acceptance Requirements for Code Compliance. The certificate of acceptance must include certification from the manufacturers of sensor devices that they will meet the requirements of §121(c)4F and that they will provide a signal that indicates the CO_2 level in the range required by §121(c)4, certification from the controls manufacturer that they respond to the type of signal that the installed sensors supply and that they can be calibrated to the CO_2 levels specified in §121(c)4, and that the CO_2 sensors have an accuracy of no lies than 75 ppm and require calibration no more frequently than once every five years.

4.4 Pipe and Duct Distribution Systems

4.4.1 Mandatory Measures

Requirements for Pipe Insulation

§123
Table 123-A

Most piping conveying either mechanically heated or chilled fluids for space conditioning or service water heating must be insulated in accordance with §123. The required thickness of piping insulation depends on the temperature of the fluid passing through the pipe, the pipe diameter, the function of the pipe within the system, and the insulation's thermal conductivity.

Standards Table 123-A specifies the requirements in terms of inches of insulation with a conductivity within a specific range. These conductivities are typical for fiberglass or foam pipe insulation. In this table, runouts are defined as being less than two inches in diameter, less than 12 feet long, and connected to fixtures or individual terminal units. Piping within fan coil units and within other heating or cooling equipment may be considered runouts for the purposes of determining the required pipe insulation.

Piping that does not require insulation includes the following:

- Factory installed piping within space-conditioning equipment certified under §111 or §112. Nationally recognized certification programs that are accepted by the Commission for certifying efficiencies of appliances and equipment are considered to meet the requirements for this exception.
- Piping that conveys fluid with a design operating temperature range between 60°F and 105°F, such as cooling tower piping or piping in water loop heat pump systems.
- Piping that serves process loads, gas piping, cold domestic water piping, condensate drains, roof drains, vents or waste piping.

Note: Designers may specify exempt piping conveying cold fluids to be insulated in order to control condensation on the surface of the pipe. Examples may include cold domestic water piping, condensate drains and roof drains. In these cases, the insulation R-value is specified by the designer and is not subject to these regulations.

- Where the heat gain or heat loss, to or from piping without insulation, will not increase building source energy use. For example, piping connecting fin-tube radiators within the same space would be exempt, as would liquid piping in a split system air conditioning unit.

This exception would not exempt piping in solar systems. Solar systems typically have backup devices that will operate more frequently if piping losses are not minimized.

- Piping that penetrates framing members shall not be required to have pipe insulation for the distance of the framing penetration. Metal piping that penetrates metal framing shall use grommets, plugs, wrapping or other insulating material to assure that no contact is made with the metal framing.

Conductivities and thicknesses listed in Standards Table 123-A are typical for fiberglass and foam. When insulating materials are used that have conductivities different from those listed here for the applicable fluid range, such as calcium silicate, Standards Equation 123-A may be used to calculate the required insulation thickness.

When a pipe carries cold fluids, condensation of water vapor within the insulation material may impair the effectiveness of the insulation, particularly for applications in very humid environments or for fluid temperatures below 40°F. Examples include refrigerant suction piping and low-temperature thermal energy storage (TES) systems. In these cases, manufacturers should be consulted and consideration given to low permeability vapor barriers, or closed-cell foams.

The Standards also require that exposed pipe insulation be protected from damage by moisture, UV and physical abrasion including but not limited to the following:

- Insulation exposed to weather shall be suitable for outdoor service; e.g., protected by aluminum, sheet metal, painted canvas, or plastic cover. Cellular foam insulation shall be protected as above or painted with a coating that is water retardant and provides shielding from solar radiation that can cause degradation of the material.
- Insulation covering chilled water piping and refrigerant suction piping located outside the conditioned space shall include a vapor retardant located outside the insulation (unless the insulation is inherently vapor retardant), all penetrations and joints of which shall be sealed.

If the conductivity of the proposed insulation does not fall into the conductivity range listed in Standards Table 123-A, the minimum thickness must be adjusted using the following equation:

Equation 4-2–Insulation Thickness

$$T = PR[(1 + t/PR)^{K/k} - 1]$$

Where:

T *Minimum insulation thickness for material with conductivity K, inches.*

PR *Pipe actual outside radius, inches.*

t *Insulation thickness, inches (from Standards Table 123-A for conductivity k).*

K *Conductivity of alternate material at the mean rating temperature indicated in Standards Table 123-A for the applicable fluid temperature range, in Btu-in./(h-ft² -°F).*

k *The lower value of the conductivity range listed in Standards Table 123-A for the applicable fluid temperature, Btu-in/(h-ft² -°F).*

Table 4-3 – Standards Table 123-A Pipe Insulation Thickness

FLUID TEMPERATURE RANGE, (°F)	CONDUCTIVITYRANGE (in Btu-inch per hour per square foot per °F)	INSULATION MEAN RATING TEMPERATURE (°F)	NOMINAL PIPE DIAMETER (in inches)					
			Runouts up to 2	1 and less	1.25-2	2.50-4	5-6	8 and larger
			INSULATION THICKNESS REQUIRED (in inches)					
Space heating systems (steam, steam condensate and hot water)								
Above 350	0.32-0.34	250	1.5	2.5	2.5	3.0	3.5	3.5
251-350	0.29-0.31	200	1.5	2.0	2.5	2.5	3.5	3.5
201-250	0.27-0.30	150	1.0	1.5	1.5	2.0	2.0	3.5
141-200	0.25-0.29	125	0.5	1.5	1.5	1.5	1.5	1.5
105-140	0.24-0.28	100	0.5	1.0	1.0	1.0	1.5	1.5
Service water-heating systems (recirculating sections, all piping in electric trace tape systems, and the first 8 feet of piping from the storage tank for nonrecirculating systems)								
Above 105	0.24-0.28	100	0.5	1.0	1.0	1.5	1.5	1.5
Space cooling systems (chilled water, refrigerant and brine)								
40-60	0.23-0.27	75	0.5	0.5	0.5	1.0	1.0	1.0
Below 40	0.23-0.27	75	1.0	1.0	1.5	1.5	1.5	1.5

Example 4-17

Question

What is the required thickness for calcium silicate insulation on a 4 inch diameter pipe carrying a 300°F fluid?

Answer

From Table 123-A in the Standards, the required insulation thickness is 2.5 inches for a 4 inch pipe in the range of 251-350°F.

The bottom of the range for mean conductivity at this temperature is listed as 0.29 (Btu-in.)/(h-ft²-°F). From manufacturer's data, it is determined that the conductivity of calcium silicate at 300°F is 0.45 Btu-in./(h-ft²-°F). The required thickness is therefore:

$$T = PR[(1 + t/PR)^{K/k} – 1]$$

$$T = 4"[(1 + 2.5/4)^{(0.045/0.29)} – 1]$$

$$T = 2.83"$$

When insulation is not available in the exact thickness calculated, the installed thickness should be the next larger available size.

Requirements for Air Distribution System Ducts and Plenums

§124

Poorly sealed or poorly insulated duct work can cause substantial losses of air volume and energy. All air distribution system ducts and plenums, including building cavities, mechanical closets, air handler boxes and support platforms used as ducts or plenums, are required to be installed, sealed, and insulated in accordance with the 2001 California Mechanical Code (CMC) Sections 601, 602, 603, 604, 605 and Standard 6-5.

Installation and Insulation

§124(a)

Portions of supply-air and return-air ducts ductwork conveying heated or cooled air located in one or more of the following spaces shall be insulated to a minimum installed level of R-8:

- Outdoors, or
- In a space between the roof and an insulated ceiling, or
- In a space directly under a roof with fixed vents or openings to the outside or unconditioned spaces, or
- In an unconditioned crawlspace; or
- In other unconditioned spaces.

Portions of supply-air ducts ductwork that are not in one of these spaces shall be insulated to a minimum installed level of R-4.2 (or any higher level required by CMC Section 605) or be enclosed in directly conditioned space. CMC insulation requirements are reproduced in Table 4-4. The following are also required:

- Mechanically fasten connections between metal ducts and the inner core of flexible ducts.
- Seal openings with mastic, tape, aerosol sealant or other duct closure system that meets the applicable requirements of UL 181, UL 181A, UL 181B or UL 723 (aerosol sealant).
- When mastic or tape is used to seal openings greater than 1/4 in., a combination of mastic and mesh or mastic and tape must be used.

Factory-Fabricated Duct Systems §124(b)1

Factory-fabricated duct systems must meet the following requirements:

- Duct and closure systems comply with UL 181, including collars, connections and splices, and must be UL labeled.
- Pressure-sensitive tapes, heat-activated tapes, and mastics used in the manufacture of rigid fiberglass ducts comply with UL 181.
- Pressure-sensitive tapes and mastics used with flexible ducts comply with UL 181 or UL 181B.
- Joints and seams of duct systems and their components shall not be sealed with cloth back rubber adhesive duct tapes unless such tape is used in combination with mastic and drawbands.

Field-Fabricated Duct Systems §124(b)2

Field-fabricated duct systems must meet the following requirements:

- Factory-made rigid fiberglass and flexible ducts for field-fabricated duct systems comply with UL 181. Pressure-sensitive tapes, mastics, aerosol sealants or other closure systems must meet applicable requirements of UL 181, UL 181A or UL 181B.

- Mastic Sealants and Mesh.
- Sealants comply with UL 181, UL 181A, or UL 181B, and must be non-toxic and water resistant.
- Sealants for interior applications pass ASTM Tests C 731(extrudability after aging) and D 2202 (slump test on vertical surfaces), incorporated herein by reference.
- Sealants for exterior applications shall pass ASTM Tests C 731, C 732 (artificial weathering test) and D 2202, incorporated herein by reference.
- Sealants and meshes shall be rated for exterior use.
- Pressure-sensitive tapes comply with UL 181, UL 181A or UL 181B.
- Drawbands used with flexible duct shall:
  - Be either stainless-steel worm-drive hose clamps or uv-resistant nylon duct ties.
  - Have a minimum tensile strength rating of 150 pounds.
  - Be tightened as recommended by the manufacturer with an adjustable tensioning tool.
- Aerosol-Sealant Closures.
  - Aerosol sealants meet applicable requirements of UL 723 and must be applied according to manufacturer specifications.
  - Tapes or mastics used in combination with aerosol sealing must meet the requirements of this section.
- Joints and seams of duct systems and their components shall not be sealed with cloth back rubber adhesive duct tapes unless such tape is used in combination with mastic and drawbands.

Duct Insulation R-Values §124(c), 124(d) & 124(e)

Since 2001, the Standards have included the following requirements for the labeling, measurement and rating of duct insulation:

- Insulation R-values shall be based on the insulation only and not include air-films or the R-values of other components of the duct system.
- Insulation R-values shall be tested C-values at 75°F mean temperature at the installed thickness, in accordance with ASTM C 518 or ASTM C 177.
- The installed thickness of duct insulation for purpose of compliance shall be the nominal thickness for duct board, duct liner, factory made flexible air ducts and factory-made rigid ducts. For factory-

made flexible air ducts, the installed thickness shall be determined by dividing the difference between the actual outside diameter and nominal inside diameter by two.

- The installed thickness of duct insulation for purpose of compliance shall be 75% of its nominal thickness for duct wrap.
- Insulated flexible air ducts must bear labels no further than 3 ft. apart that state the installed R-value (as determined per the requirements of the Standards).

A typical duct wrap, nominal 1-1/2 inch and 0.75 pcf will have an installed rating of R-4.2 with 25% compression.

Protection of Duct Insulation §124(f)

The Standards require that exposed duct insulation be protected from damage by moisture, UV and physical abrasion including but not limited to the following:

- Insulation exposed to weather shall be suitable for outdoor service; e.g., protected by aluminum, sheet metal, painted canvas, or plastic cover.
- Cellular foam insulation shall be protected as above or painted with a coating that is water retardant and provides shielding from solar radiation that can cause degradation of the material.

Example 4-18

Question

What are the sealing requirements in a VAV system having a static pressure setpoint of 1.25” w.g. and a plenum return?

Answer

All duct work located within the return plenum must be sealed in accordance with the California Mechanical Code (CMC) Sections 601, 602, 603, 604 and 605 (refer to §124). Pressure-sensitive tape, heat-seal tape and mastic may be used, if it meets the applicable requirement of UL 181, 181A, 181B, to seal joints and seams which are mechanically fastened per the CMC.

Table 4-4 – Duct Insulation Requirements

DUCT LOCATION [1]	INSULATION R-VALUE MECHANICALLY COOLED	HEATING ZONE	INSULATION R-VALUE HEATING ONLY
On roof on exterior building	6.3	< 4,500 DD	2.1
		< 8,000 DD	4.2
Attics, garages, and crawl spaces	2.1	< 4,500 DD	2.1
		< 8,000 DD	4.2
In walls [2] and within floor to ceiling spaces [2]	2.1	< 4,500 DD	2.1
		< 8,000 DD	4.2
Within the conditioned space or in basements; return ducts in air plenums	None Required		None Required
Cement slab or within ground	None Required		None Required

[1] Vapor barriers shall be installed on supply ducts in spaces vented to the outside in geographic areas where the average July, August and September mean dew point temperature exceeds 60 degrees Fahrenheit.

[2] Insulation may be omitted on that portion of a duct which is located within a wall or a floor to ceiling space where:

a. Both sides of the space are exposed to conditioned air.
b. The space is not ventilated.
c. The space is not used as a return plenum.
d. The space is not exposed to unconditioned air.

Ceilings which form plenums need not be insulated.

NOTE: Where ducts are used for both heating and cooling, the minimum insulation shall be as required for the most restrictive condition.

Source: Uniform Mechanical Code §605

4.4.2 Prescriptive Requirements

Duct Leakage

Ducts on small single zone systems with portions of the ductwork either out of doors or in uninsulated or vented ceiling spaces are required to be sealed and leak tested [§144(k) and §125]. This will generally only apply to small commercial projects that are one or two stories with packaged single zone units or split systems. Duct leakage testing only applies when all of the following are true:

- The system is constant volume.
- It serves less than 5000 ft^2 of conditioned space.
- 25% or more of the duct surface area is located in the outdoors, unconditioned space, a ventilated attic, in a crawl space or where the U-factor of the roof is greater than the U-factor of the ceiling [except where the roof meets with the requirements of §143(a)1C].

Where duct sealing and leakage testing is required, the ducts must be tested by a HERS certified agency to demonstrate a leakage rate of ≤6% of fan flow.

§149(b)1D requires that duct sealing apply to new ducts on existing systems and existing ducts on existing systems that are being either repaired or replaced. Where an entirely new duct system is being installed, and meets the criteria previously described it must meet or exceed the leakage rate of ≤ 6% of fan flow.

If the new ducts are an extension of an existing duct system the combined system (new and existing ducts) must meet:

- A leakage rate of < 15% of fan flow, or
- A reduction in leakage rate of ≥ 60% (as compared to the existing ductwork) with all “accessible” leaks demonstrated through visual inspection to have been sealed, or
- All accessible leaks shall be sealed and verified through a visual inspection by a certified HERS rater.

There is an exception for ducts that are connected to existing ducts with asbestos insulation or sealant.

These requirements also apply to cases where existing HVAC equipment is either repaired or replaced. With exceptions for ducts that are insulated or sealed with asbestos and an existing duct system that has previously been leakage tested by a certified California HERS rater (see http://www.energy.ca.gov/HERS/).

One can avoid sealing the ducts by insulating the roof and sealing the attic vents as part of a larger remodel, thereby creating a conditioned space within which the ducts are located, and no longer meets the criteria of §144 k.

Another alternative to duct sealing is to install a high efficiency air conditioner that will save as much energy as the duct system is losing though leaks. This trade-off can be calculated using the performance software or by using pre-calculated equipment efficiencies deemed comparable to duct sealing. In climate zones 1-15, systems with air conditioner efficiencies at least as high as those in Table 4-5 are deemed equivalent to duct sealing.

Section 4.4.3 describes mandated acceptance test requirements for ductwork.

Table 4-5 – Single Zone Air-Conditioner Efficiency Deemed Comparable to Duct Sealing

	Air conditioner		Heat Pump	
	< 65,000 Btu/h	≥ 65,000 Btu/h	< 65,000 Btu/h	≥ 65,000 Btu/h
CTZ	SEER/EER	EER	SEER/EER	EER
1	13.5/11.2	11.3	13.0/10.6	11.0
2	13.8/11.4	11.5	13.3/11.0	11.5
3	13.2/11.0	11.1	13.0/10.7	11.0
4	13.4/11.1	11.3	13.1/10.9	11.2
5	13.2/11.0	11.0	13.0/10.8	11.0
6	13.1/10.9	11.0	13.1/10.9	11.0
7	13.3/11.0	11.1	13.3/11.0	11.1
8	13.5/11.2	11.3	13.4/11.1	11.3
9	13.7/11.4	11.4	13.6/11.3	11.4
10	13.9/11.5	11.7	13.9/11.5	11.7
11	14.2/11.8	11.9	13.3/11.0	11.7
12	14.0/11.6	11.9	13.3/11.0	11.9
13	14.3/11.9	12.0	13.7/11.4	11.9
14	14.2/11.8	12.0	13.6/11.3	11.9
15	14.5/12.0	12.1	14.5/12.0	12.1
16	14.0/11.6[1]	12.1[1]	13.0/10.8	11.7

1. In climate zone 16, the equivalent efficiency system must have high efficiency heating system in addition to the minimum air conditioner efficiency In Table 4-5. A high heating efficiency system has a minimum thermal efficiency of 96% or an AFUE of 94% for furnaces and a minimum HSPF of 8.4 or a COP of 3.8 for heat pumps.

Example 4-19

Question

A new 20 ton single zone system with new ductwork serving an auditorium is being installed. Approximately ½ of its ductwork on the roof. Does it need to be leak tested?

Answer

Probably not. Although this system meets the criteria of being single zone and having more than ¼ of the duct surface area on the roof, the unit probably serves more than 5,000 ft^2 of space. Most 15 and 20 ton units will serve spaces that are significantly larger than 5,000 ft^2. If the space is 5,000 ft^2 or less the ducts do need to be leak tested per §144(k).

Example 4-20

Question

A new 5 ton single zone system with new ductwork serving a 2,000 ft^2 office is being installed. The unit is a down discharge configuration and the roof has insulation over the deck. Does the ductwork need to be leak tested?

Answer

Probably not. Although this system meets the criteria of being single zone and serving less than 5,000 ft^2 of space, it does not have ¼ of its duct area in one of the spaces listed in §144(k). With the insulation on the roof and not on the ceiling, the plenum area likely meets the criteria of indirectly conditioned so no leakage testing is required.

Example 4-21

Question

A 5 ton single zone packaged rooftop unit with existing ductwork serving a 2,000 ft^2 office is being replaced. The unit is a down discharge configuration but the ductwork runs between an uninsulated roof and an insulated dropped ceiling. Does the ductwork need to be leak tested?

Answer

Most likely it will. This system meets the criteria of being single zone and serving less than 5,000 ft^2 of space. It also likely has more than ¼ of its duct area in the space between the uninsulated roof and the insulated ceiling. This space does not pass the U-factor criteria (i.e., the U-factor of the roof is more than the U-factor of the ceiling. Per §149(b)1D the ductwork will need to be sealed and leak tested to provide leakage ≤ 15% of fan flow.

4.4.3 Acceptance Requirements

The Standards have acceptance requirements where duct sealing and leakage testing is required by §144(k).

These tests are described in the Chapter 8, Acceptance Requirements, and the Nonresidential ACM Manual in Appendices NG and NJ. The rater will also perform the leakage tests that are described in Appendix NG-2005 of the Nonresidential ACM Manual.

4.5 HVAC System Control Requirements

4.5.1 Mandatory Measures

This section covers controls that are mandatory for all system types, including:

- Heat pump controls for the auxiliary heaters,
- Zone thermostatic control including special requirements for hotel/motel guest rooms and perimeter systems,
- Shut-off and setback/setup controls,
- Infiltration control,
- Off-hours space isolation, and
- Control equipment certification.

Heat Pump Controls

§112(b)

Heat pumps with electric resistance supplemental heaters must have controls that limit the operation of the supplemental heater to defrost and as a second stage of heating when the heat pump alone cannot satisfy the load. The most effective solution is to specify an electronic thermostat designed specifically for

This requirement can also be met using conventional electronic controls with a two-stage thermostat and an outdoor lockout thermostat wired in series with the auxiliary heater. The outdoor thermostat must be set to a temperature where the heat pump capacity is sufficient to warm up the space in a reasonable time (e.g., above 40°F). This conventional control system is depicted schematically in Figure 4-9 below.

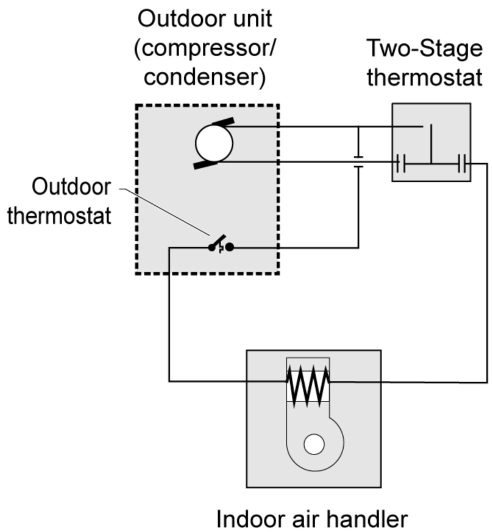


Figure 4-9 – Heat Pump Auxiliary Heat Control, Two-Stage and Outdoor Air Thermostats

Zone Thermostatic Controls

[§122(a), (b) and (c)]

Thermostatic controls must be provided for each space-conditioning zone or dwelling unit to control the supply of heating and cooling energy within that zone [§122(a)]. The controls must have the following characteristics:

- When used to control **heating**, the thermostatic control must be adjustable down to 55°F or lower.
- When used to control **cooling**, the thermostatic control must be adjustable up to 85°F or higher.
- When used to control both **heating and cooling**, the thermostatic control must be adjustable from 55°F to 85°F and also provide a temperature range or **dead band** of at least 5°F. When the space temperature is within the deadband, heating and cooling energy must be shut off or reduced to a minimum. A dead band is not required if the thermostat requires a manual changeover between the heating and cooling modes §122(b) Exception No. 1.

The setpoint may be adjustable either locally or remotely, by continuous adjustment or by selection of sensors.

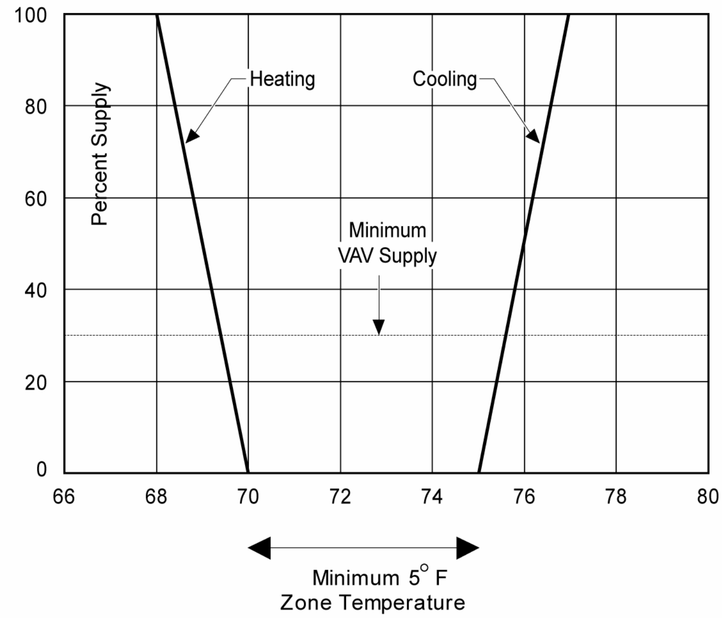


Figure 4-10 – Proportional Control Zone Thermostat

Example 4-22

Question

Can an energy management system be used to control the space temperatures?

Answer

Yes, provided the space temperature setpoints can be adjusted, either locally or remotely. This section sets requirements for "thermostatic controls" which need not be a single device like a thermostat; the control system can be a broader system like a direct digital control (DDC) system. Note that some DDC systems employ a single cooling setpoint and a fixed or adjustable deadband. These systems comply if the deadband is adjustable or fixed at 5°F or greater.

Thermostats with adjustable setpoints and deadband capability are not required for zones that must have constant temperatures to prevent the degradation of materials, a process, or plants or animals §122(b) Exception No. 2. Included in this category are computer rooms, clean rooms, hospital patient rooms, museums, etc.

Chapter 8 describes mandated acceptance test requirements for thermostat control for packaged HVAC systems.

Hotel/Motel Guest Rooms and High-Rise Residential Dwellings Thermostats

§122(c)

The Standards require that thermostats in hotel and motel guest rooms have:

- Numeric temperature setpoints in °F, and
- Setpoint stops that prevent the thermostat from being adjusted outside the normal comfort range. These stops must be concealed so that they are accessible only to authorized personnel.

The Standards effectively prohibit thermostats having ‘warmer/cooler’ or other labels with no temperature markings in this type of occupancy [§122(c)].

The Standards require [§122(c)] that thermostats in High-rise residential dwelling units must have setback capabilities and meet all the requirements in §150(i).

Perimeter Systems Thermostats

Supplemental perimeter heating or cooling systems are sometimes used to augment a space-conditioning system serving both interior and perimeter zones. This is allowed by §122(a) Exception, provided controls are incorporated to prevent the two systems from conflicting with each other. If that were the case, then the Standards require that:

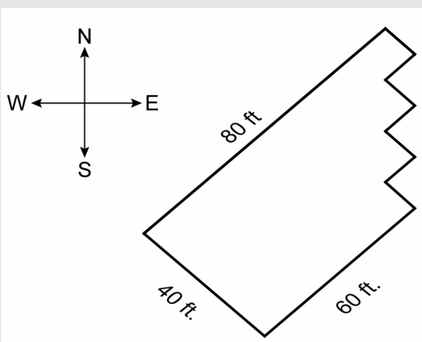
- The perimeter system must be designed solely to offset envelope heat losses or gains; and
- The perimeter system must have at least one thermostatic control for each building orientation of 50 ft. or more; and
- The perimeter system is controlled by at least one thermostat located in one of the zones served by the system.

The intent is that all major exposures be controlled by their own thermostat, and that the thermostat be located within the conditioned perimeter zone. Other temperature controls, such as outdoor temperature reset or solar compensated outdoor reset, do not meet these requirements of the Standards.

Example 4-23

Question

What is the perimeter zoning required for the building shown here?



Answer

The southeast and northwest exposures must each have at least one perimeter system control zone, since they are more than 50 ft. in length. The southwest exposure and the serrated east exposure do not face one direction for more than 50 continuous ft. in length. They are therefore “minor” exposures and need not be served by separate perimeter system zones, but may be served from either of the adjacent zones.

Example 4-24

Question

Pneumatic thermostats are proposed to be used for zone control. However, the model specified cannot be adjusted to meet the range required by §122(a) to (c). How can this system comply?

Answer

Section 122(a) to (c) applies to “thermostatic controls” which can be a system of thermostats or control devices, not necessarily a single device. In this case, the requirement could be met by using multiple thermostats. The pneumatic thermostats could be used for zone control during occupied hours and need only have a range consistent with occupied temperatures (e.g. 68°F to 78°F), while two additional electric thermostats could be provided, one for setback control (adjustable down to 55°F) and one for set-up (adjustable up to 85°F). These auxiliary thermostats would be wired to temporarily override the system to maintain the setback/setup setpoints during off-hours.

Shut-off and Temperature Setup/Setback

§122(e)

For specific occupancies and conditions, each space-conditioning system must be provided with controls that can automatically shut off the equipment during unoccupied hours. The control device can be either:

- An automatic time switch device must have the same characteristics that lighting devices must have, as described in §119(c). This can be accomplished with a seven-day programmable thermostat with a battery backup of at least 10 hours.

  A manual override accessible to the occupants must be included in the control system design either as a part of the control device, or as a separate override control. This override shall allow the system to operate up to four hours during normally unoccupied periods.

- An occupancy sensor. Since a building ventilation purge is required prior to normal occupancy [§121(c)2], an occupancy sensor may be used to control the availability of heating and cooling, but should not be used to control the outdoor ventilation system.

  When an automatic time switch is used to control ventilation while occupancy sensors are used simultaneously to control heating and cooling, the controls should be interlocked so that ventilation is provided during off-hours operation.

  Where ventilation is provided by operable openings (see discussion on natural ventilation in Section 4.3 above) an occupant sensor can be used without interlock.

- A four-hour timer that can be manually operated to start the system. As with occupancy sensors, the same restrictions apply to controlling outdoor air ventilation systems.

When shut down, the controls shall automatically restart the system to maintain:

- A setback heating thermostat setpoint, if the system provides mechanical heating. Thermostat setback controls are not required in areas where the Winter Median of Extremes outdoor air temperature is greater than 32°F [§122(e)2.A and Exception].

- A setup cooling thermostat setpoint, if the system provides mechanical cooling. Thermostat setup controls are not required in areas where the Summer Design Dry Bulb 0.5% temperature is less than 100°F [§122(e)2.B and Exception].

Example 4-25

Question

Can occupancy sensors be used in an office to shut off the VAV boxes during periods the spaces are unoccupied?

Answer

Only if the ventilation is provided through operable openings. With a mechanical ventilation design the occupancy sensor could be used to reduce the VAV box airflow to the minimum allowed for ventilation. It should not shut the airflow off completely, because §121(c) requires that ventilation be supplied to each space at all times when the space is usually occupied.

Example 4-26

Question

Must a 48,000 ft^2 building with 35 fan coil units have 35 time switches?

Answer

No. More than one space-conditioning system may be grouped on a single time switch, subject to the area limitations required by the isolation requirements (see Isolation). In this case, the building would need two isolation zones, each no larger than 25,000 ft^2, and each having its own time switch.

Example 4-27

Question

Can a thermostat with setpoints determined by sensors (such as a bi-metal sensor encased in a bulb) be used to accomplish a night setback?

Answer

Yes. The thermostat must have two heating sensors, one each for the occupied and unoccupied temperatures. The controls must allow the setback sensor to override the system shutdown.

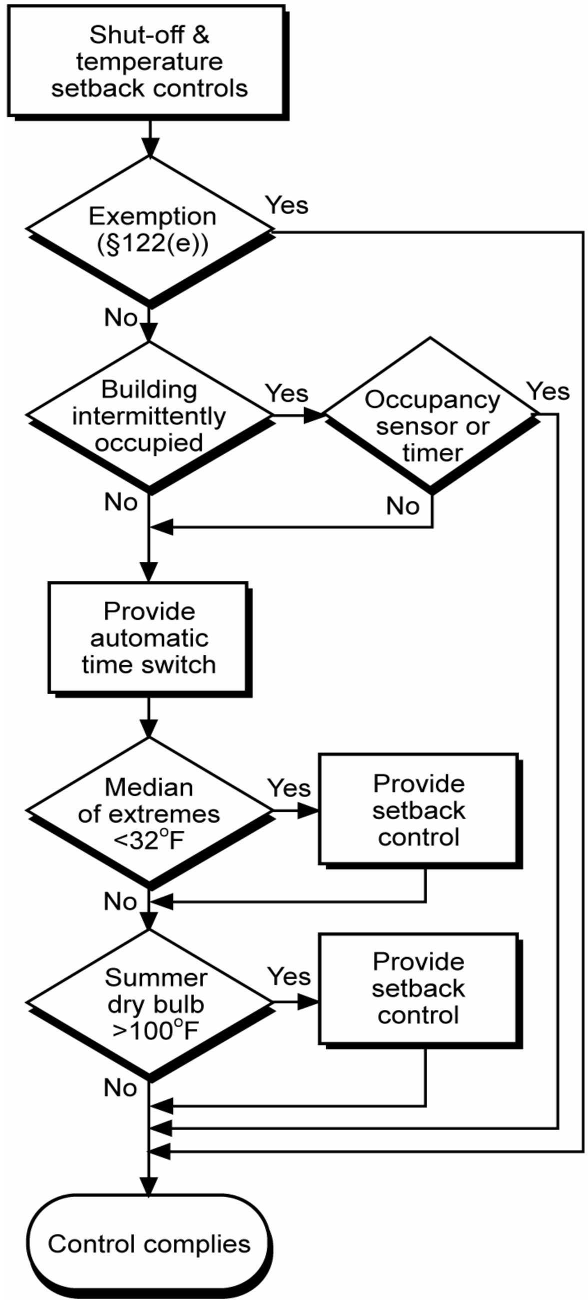


Figure 4-11 – Shut-Off and Setback Controls Flowchart

These provisions are required by the Standards to reduce the likelihood that shut-off controls will be circumvented to cause equipment to operate continuously during unoccupied hours.

Automatic shut-off, setback and setup devices are not required where:

- It can be demonstrated to the satisfaction of the enforcement agency that the system serves an area that must operate continuously [§122(e) Exception No. 1]; or

- It can be demonstrated to the satisfaction of the enforcement agency that shutdown, setback, and setup will not result in a decrease in overall building source energy use [§122(e) Exception No. 2)]; or
- *Systems* have a full load demand less than 2 kW, or 6,826 Btu/h, if they have a readily accessible manual shut-off switch [§122(e) Exception No. 3]. Included is the energy consumed within all associated space-conditioning systems including compressors, as well as the energy consumed by any boilers or chillers that are part of the system.
- Systems serve hotel/motel guest rooms, if they have a readily accessible manual shut-off switch [§122(e) Exception No.4].
- The mechanical system serves retail stores and associated malls, restaurants, grocery stores, churches, or theaters equipped with a seven-day programmable timer.

Example 4-28

Question

If a building has a system comprised of 30 fan coil units, each with a 300-watt fan, a 500,000 Btu/h boiler, and a 30-ton chiller, can an automatic time switch be used to control only the boiler and chiller (fan coils operate continuously)?

Answer

No. The 2 kW criteria applies to the system as a whole, and is not applied to each component independently. While each fan coil only draws 300 W, they are served by a boiler and chiller that draw much more. The consumption for the system is well in excess of 2 kW.

Assuming the units serve a total area of less than 25,000 ft^2 (see Isolation), one time switch may control the entire system.

Infiltration Control

§122(f)

Outdoor air supply and exhaust equipment must incorporate dampers that automatically close when fans shut down. The dampers may either be motorized, or of the gravity type.

Damper control is not required where it can be demonstrated to the satisfaction of the enforcement agency that the space-conditioning system must operate continuously [§122(f) Exception No. 1]. Nor is damper control required on gravity ventilators or other non-electrical equipment, provided that readily accessible manual controls are incorporated [§122(f) Exception No. 2].

Damper control is also not required at combustion air intakes and shaft vents, or where prohibited by other provisions of law [§122(f) Exceptions No. 3 and 4]. If the designer elects to install dampers or shaft vents to help control stack-induced infiltration, the damper should be motorized and controlled to open in a fire in accordance with applicable fire codes.

Isolation Area Controls

§122(g)

Large space-conditioning systems serving multiple zones may waste considerable quantities of energy by conditioning all zones when only a few zones are occupied. Typically, this occurs during evenings or weekends when only a few people are working. When the total area served by a system exceeds 25,000 ft^2, the Standards require that the system be designed, installed and controlled with area isolation devices to minimize energy consumption during these times. The requirements are:

- The building shall be divided into isolation areas, the area of each not exceeding 25,000 ft^2. An isolation area may consist of one or more zones.
- An isolation area cannot include spaces on different floors.
- Each isolation area shall be provided with isolations devices such as valves or dampers that allow the supply of heating or cooling to be setback or shut off independently of other isolation areas.
- Each isolation area shall be controlled with an automatic time switch, occupancy sensor, or manual timer. The requirements for these shut-off devices are the same as described previously in §122(e)1. As discussed previously for occupancy sensors, a building purge must be incorporated into the control sequences for normally occupied spaces, so occupancy sensors and manual timers are best limited to use in those areas that are intermittently occupied.

Any zones requiring continuous operation do not have to be included in an isolation area.

Example 4-29

Question

How many isolation zones does a 55,000-ft^2 building require?

Answer

At least three. Each isolation zone may not exceed 25,000-ft^2.

Isolation of Zonal Systems

Small zonal type systems such as water loop heat pumps or fan coils may be grouped on automatic time switch devices, with control interlocks that start the central plant equipment whenever any isolation area is occupied. The isolation requirements apply to equipment supplying heating and cooling only; central ventilation systems serving zonal type systems do not require these devices.

Isolation of Central Air Systems

Figure 4-12 below depicts four methods of area isolation with a central variable air volume system:

- On the lowest floor programmable DDC boxes can be switched on a separate time schedule for each zone or blocks of zones. When unoccupied, the boxes can be programmed to have zero minimum volume setpoints and unoccupied setback/setup setpoints. Note this form of isolation can be used for sections of a single floor distribution system.
- On the second floor, normally closed pneumatic or electric VAV boxes are used to isolate zones or groups of zones. In this scheme the control source (pneumatic air or control power) for each group is switched on a separate control signal from an individual time schedule. Again this form of isolation can be used for sections of a single floor distribution system.
- On the third floor isolation is achieved by inserting a single motorized damper on the trunk of the distribution ductwork. With the code requirement for fire/smoke dampers (see next bullet) this method is somewhat obsolete. When applied this method can only control a single trunk duct as a whole. Care must be taken to integrate the motorized damper controls into the fire/life safety system.
- On the top floor a combination fire smoke damper is controlled to provide the isolation. Again this control can only be used on a single trunk duct as a whole. Fire/smoke dampers required by code can be used for isolation at virtually no cost provided that they are wired so that the fire life-safety controls take precedence over off-hour controls. (Local fire officials generally allow this dual usage of smoke dampers since it increases the likelihood that the dampers will be in good working order in the event of a fire.)

Note that no isolation devices are required on the return.

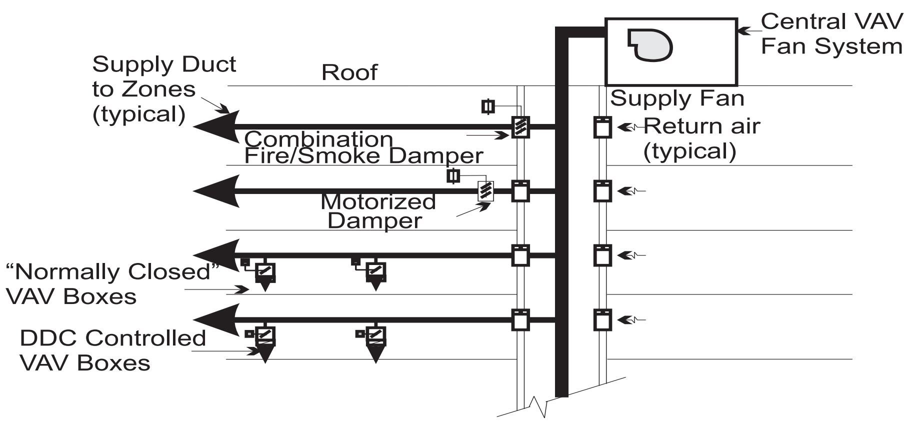


Figure 4-12– Isolation Methods for a Central VAV System

Example 4-30

Question

Does each isolation area require a ventilation purge?

Answer

Yes. Consider each isolation area as if it were a separate air handling system, each with its own time schedule, setback and setup control, etc.

Turndown of Central Equipment

Where isolation areas are provided it is critical that the designer design the central systems (fans, pumps, boilers and chillers) to have sufficient stages of capacity or turndown controls to operate stably as required to serve the smallest isolation area on the system. Failure to do so may cause fans to operate in surge, excessive equipment cycling and loss of temperature control. Schemes include:

- Application of demand based supply pressure reset for VAV fan systems. This will generally keep variable speed driven fans out of surge and can provide 10:1 turndown.
- Use of pony chillers, an additional small chiller to be used at partial load conditions, or unevenly split capacities in chilled water plants. This may be required anyway to serve 24/7 loads.
- Unevenly split boiler plants.

Control Equipment Certification

§119(d)

Where used in HVAC systems, occupancy sensors must be certified to the Energy Commission prior to specification or use that they comply with the requirements of §119(d). These requirements are described in Chapter 5.

Automatic time switches must meet the requirements of §119(c). These also are described in Chapter 5. When used solely for mechanical controls they are not required to be certified by the Energy Commission. Most standard programmable thermostats and DDC system comply with these requirements. Time controls for HVAC systems must have a readily accessible manual override that can provide up to four hours of off-hour control.

CO_2 sensors used in DCV systems used to require certification to and approval by the CEC. This has been replaced by certification by the manufacture [§121(c) 4.F.] and the acceptance requirements described in Section 4.3 Ventilation Requirements.

4.5.2 Prescriptive Requirements

Space Conditioning Zone Controls

§144(d)

Each space-conditioning zone shall have controls that prevent:

- Reheating of air that has been previously cooled by mechanical cooling equipment or an economizer.
- Recooling of air that has been previously heated. This does not apply to air returned from heated spaces.
- Simultaneous heating and cooling in the same zone, such as mixing or simultaneous supply of air that has been previously mechanically heated and air that has been previously cooled, either by cooling equipment or by economizer systems.

These requirements do not apply to zones having:

- VAV controls, as discussed in the following section.
- Special pressurization relationships or cross contamination control needs. Laboratories are an example of spaces that might fall in this category.
- Site-recovered or site-solar energy providing at least 75% of the energy for reheating, or providing warm air in mixing systems.
- Specific humidity requirements to satisfy process needs.
- 300 cfm or less peak supply air quantity. This exception allows reheating or recooling to be used in small sub-zones served by constant volume systems.

VAV Zone Controls

§144(d) Exception No. 1

Section 144(d) limits the highest allowable minimum airflow setpoints in order to minimize reheat energy. The minimum setpoint must be no greater than the largest of the following:

- 30% of the peak supply volume; or
- The minimum required to meet the ventilation requirements of §121; or
- 0.4 cfm per ft^2 of conditioned floor area of the zone; or
- 300 cfm.

The first limit, 30% of the maximum supply air, is intended to provide sufficient airflow to VAV system diffusers to minimize stratification, dumping, and short-circuiting.

The second limit is to ensure minimum ventilation rates can be maintained. Note that since the Standards allow air transferred or returned from other ventilated spaces to be used for ventilation, the minimum airflow setpoint need not be adjusted for the fraction of "fresh" air that is in the supply air. In other words, if the minimum ventilation rate is 0.15 cfm/ft^2, then the minimum airflow setpoint may be set to that value even if the supply air is not 100% outdoor air, provided the design minimum outdoor air at the air handler is delivered to some other spaces served by the system. Also note that unless transfer air is provided, e.g. from a fan-powered mixing box, this second criterion also is the lowest minimum airflow setpoint allowed by the Standards since ventilation rates must be maintained whenever the space is expected to be occupied.

The third limit, 0.4 cfm/ft^2, is provided to provide a minimum amount of air circulation, which many designers feel is needed for comfort. However, research and field studies have shown that there is very little correlation between airflow and comfort, and that most complaints of "stuffiness" are actually driven by space temperature.

The fourth limit, 300 cfm, is provided to allow for a few small constant volume subzones such as a lobby served off of an adjacent office zone.

In common practice, VAV box minimums are set much higher than they need to be. In the buildings surveyed as part of recent research[8] the box minimums ranged between 30 and 50% of design airflow, despite Standards limits that require lower values. Unfortunately, this common practice significantly increases reheat fan, and cooling energy usage.

Where VAV boxes have direct digital controls, energy can be saved by employing a "dual-maximum" VAV box control. This is depicted in Figure 4-13 below. In cooling, this control scheme is similar to a traditional VAV reheat box control. The difference is what occurs in the deadband between heating and cooling and in the heating mode. With traditional VAV control logic, the minimum airflow rate is typically set to the largest rate allowed by code. This airflow rate is supplied to the space in the deadband and heating modes. With the dual maximum logic, the minimum rate is the lowest allowed by code (e.g. the minimum ventilation rate) or the minimum rate the controls system can be set to (which is a function of the VAV box velocity pressure sensor amplification factor and the accuracy of the controller to convert the velocity pressure into a digital signal). As the heating demand increases, the dual maximum control first resets the discharge air temperature (typically from the design cold deck temperature up to 85 or 90°F) as a first stage of heating then, if more heat is required, it increases airflow rate up to a "heating" maximum airflow setpoint, which is the same value as what traditional control logic uses as the minimum airflow setpoint. Using this control can save significant fan, reheat and cooling energy while maintaining better ventilation effectiveness as the discharge heating air is controlled to a temperature that will minimize stratification.

This control requires a discharge air sensor and may require a programmable VAV box controller. The discharge air sensor is very useful for diagnosing control and heating system problems even if they are not actively used for control.

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[8] Part of a Public Interest Energy Research (PIER) project.

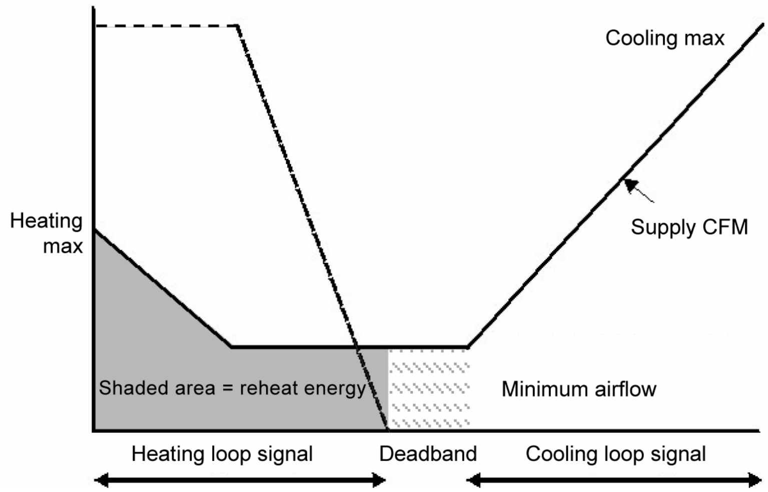


Figure 4-13 – Dual-Maximum VAV Box Control Diagram

Example 4-31

Question

What are the limitations on VAV box minimum airflow setpoint for a 1000 ft^2 office having a design supply of 1100 cfm and eight people?

Answer

Based on reheat requirements, the minimum cfm cannot exceed the larger of:

a. 1100 cfm x 30% = 330 cfm; or

b. The minimum ventilation rate which is the larger of

1) 1000 ft² x 0.15 cfm/ft² = 150 cfm; and

2) 8 people x 15 cfm/person = 120 cfm

c. 1000 ft² x 0.4 cfm/ft² = 400 cfm; and

d. 300 cfm

Thus the minimum airflow setpoint can be no larger than 400 cfm.

Based on ventilation requirements, the lowest minimum airflow setpoint must be at least 150 cfm, or transfer air must be provided in this amount.

Economizers

§144(e)

An economizer must be fully integrated and must be provided for each individual cooling space-conditioning system that has a design supply capacity over 2,500 cfm and a total cooling capacity over 75,000 Btu/h. The economizer may be either:

- An air economizer capable of modulating outside air and return air dampers to supply 100% of the design supply air quantity as outside air; or

- A water economizer capable of providing 100% of the expected system cooling load at outside air temperatures of 50°F dry-bulb and 45°F wet-bulb and below.

Depicted below in Figure 4-14 is a schematic of an air-side economizer. All air-side economizers have modulating dampers on the return and outdoor air streams. To maintain acceptable building pressure, systems with airside economizer must have provisions to relieve or exhaust air from the building. In Figure 4-14, three common forms of building pressure control are depicted: Option 1 barometric relief, Option 2 a relief fan generally controlled by building static pressure, and Option 3 a return fan often controlled by tracking the supply.

Figure 4-22 depicts an integrated air-side economizer control sequence. On first call for cooling the outdoor air damper is modulated from minimum position to 100% outdoor air. As more cooling is required, the damper remains at 100% outdoor air as the cooling coil is sequenced on.

Graphics of water-side economizers are presented in Section 4.10 Glossary/Reference at the end of this chapter.

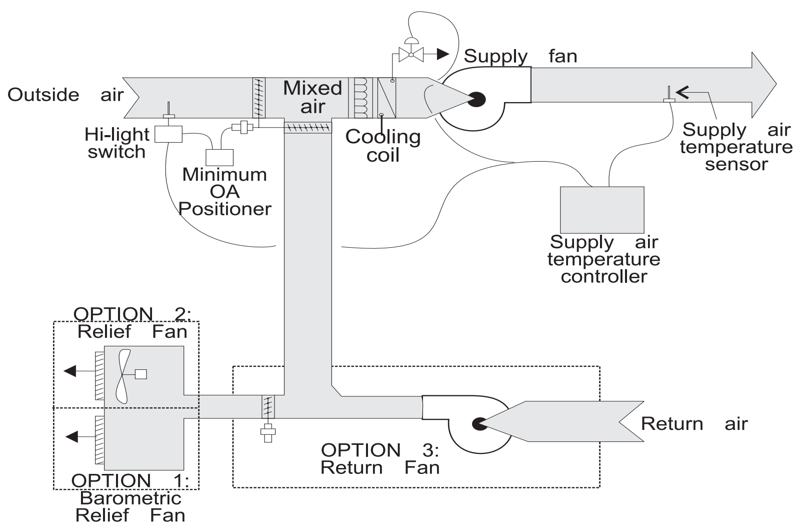


Figure 4-14 – Air-Side Economizer Schematic

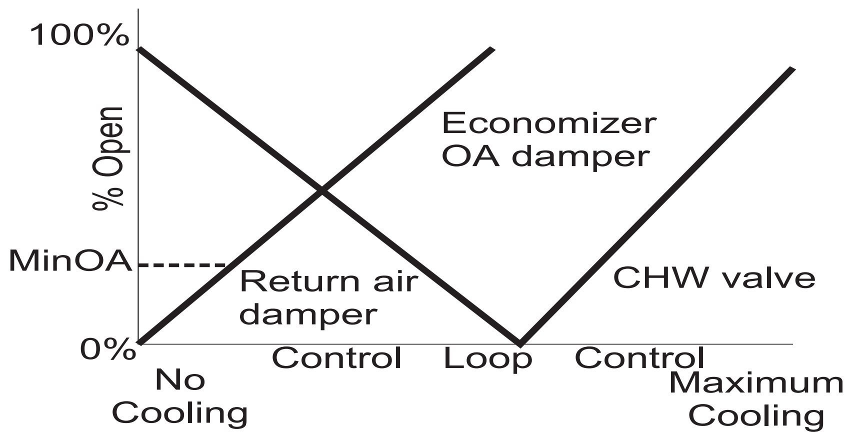


Figure 4-15 – Typical Air-Side Economizer Control Sequencing

Economizers are not required where:

- Outside air filtration and treatment for the reduction and treatment of unusual outdoor contaminants make compliance infeasible. This must be demonstrated to the satisfaction of the enforcement agency.
- Increased overall building TDV energy use results. This may occur where economizers adversely impact other systems, such as humidification, dehumidification or supermarket refrigeration systems.
- Systems serving high-rise residential living quarters and hotel/motel guest rooms. Note that these buildings typically have systems smaller than 2,500 cfm, and also have provisions for natural ventilation.
- Where it can be shown to the satisfaction of the enforcing agency that the use of outdoor air is detrimental to equipment or materials in a space or room served by a dedicated space conditioning system, such as a computer room or telecommunications equipment room.
- If cooling capacity is less than or equal to 75,000 Btu/h, or supply airflow is less than or equal to 2,500 cfm.
- When unitary air-conditioners or heat pumps have a rated efficiency that meets or exceeds the efficiency levels in Standards Table 144-A for unitary air-conditioners and (§144-B for unitary heat pumps. These tables present trade-off efficiency levels by climate zone (left column) and equipment size category (top row). Table cells marked with “N/A” for “not applicable” represent combinations of climate zones and size categories for which there is no trade-off available (i.e. and air-side economizer is always required).

If an economizer is required, it must be designed and equipped with controls that do not increase the building heating energy use during normal operation. This prohibits the application of single-fan dual-duct systems and traditional multizone systems using the Prescriptive Approach of compliance (see Figure 4-17). With these systems the operation of the economizer to pre-cool the air entering the cold deck also precools the air entering the hot deck and thereby increases the heating energy. An exception allows these systems when at least 75% of the annual heating is provided by site-recovered or site-solar energy §144(e)2.A.

The economizer controls must also be fully *integrated* into the cooling system controls so that the economizer can provide partial cooling even when mechanical cooling is required to meet the remainder of the load §144(e)2.B. On packaged units with stand-alone economizers, a two-stage thermostat is necessary to meet this requirement.

The requirement that economizers be designed for concurrent operation is not met by some popular water economizer systems, such as those that use the chilled water system to convey evaporative-cooled condenser water for “free” cooling. Such systems can provide 100% of the cooling load, but when the point is reached where condenser water temperatures cannot be sufficiently cooled by evaporation, the system controls throw the entire load to the mechanical chillers. Because this design cannot allow simultaneous economizer and refrigeration system operation, it does not meet the requirements of this section.

Air-side economizers are required to have high-limit shut-off controls that comply with Table 144-C of the Standards. This table has four columns:

1. The first column identifies the high limit control category. There are five categories representing enthalpy and dry-bulb controls (fixed and differential and the electronic enthalpy controller.

2. The second column represents the California climate zone. “All” indicates that this control type complies in every California climate.

3. The third and fourth columns present the high-limit control setpoints required.

Fixed enthalpy controls are prohibited in climate zones 01, 02, 03, 05, 11, 13, 14, 15 & 16. In these climates, the enthalpy in the return air varies throughout the year and cannot be accurately represented by a fixed setpoint.

Air economizers, water economizers and integrated controls are discussed in more detail at the beginning of this Chapter.

Chapter 8, Acceptance Requirements, describe mandated acceptance test requirements for economizers.

To reduce the time required to perform the economizer acceptance test, factory calibration and a calibration certificate of economizer control sensors (outdoor air temperature, return air temperature, etc.

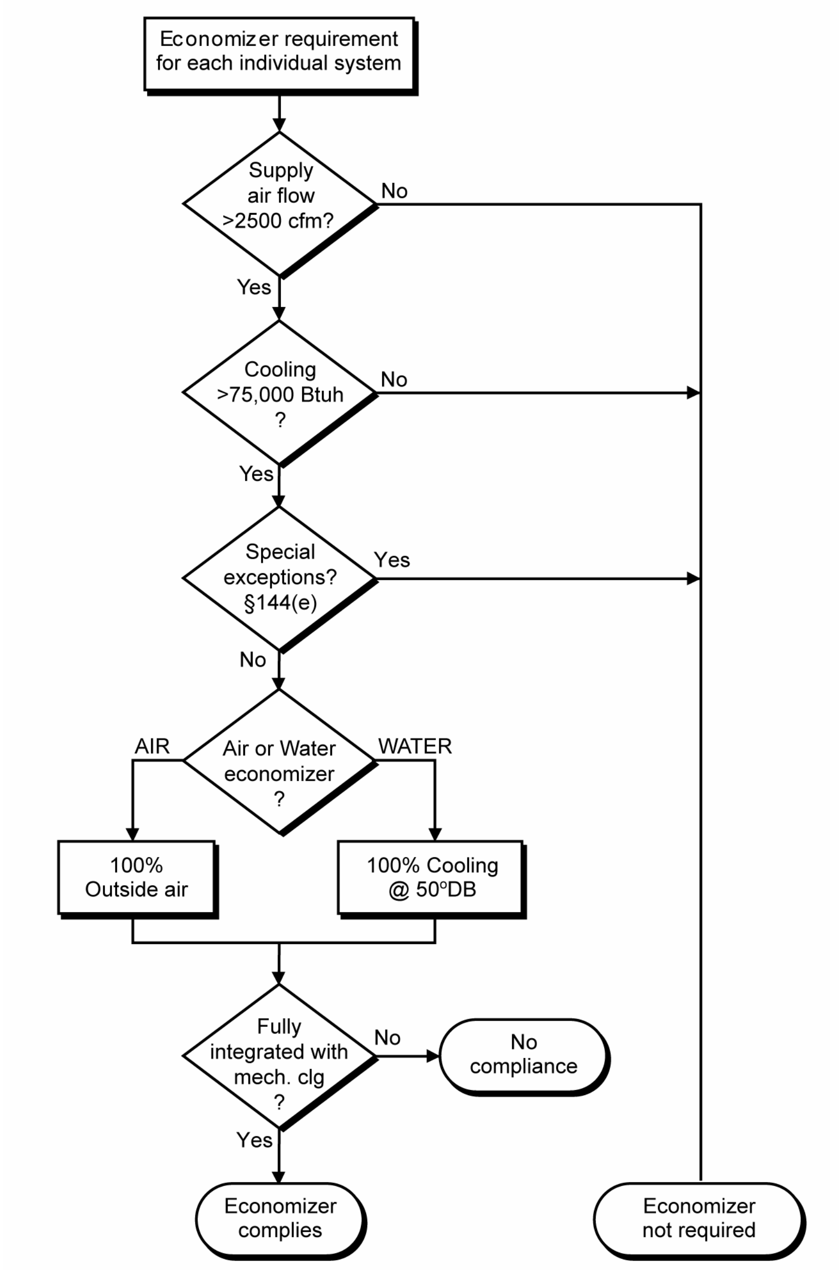


Figure 4-16 – Economizer Flowchart

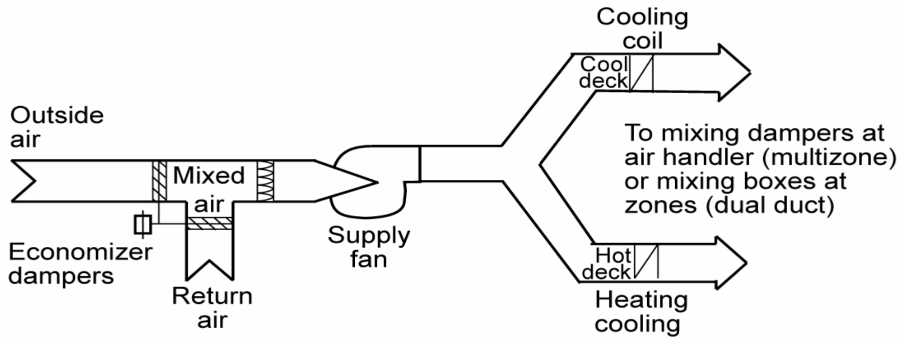


Figure 4-17 – Single-Fan Dual-Duct System

Example 4-32

Question

If my design conditions are 94°Fdb/82°Fwb can I use my design cooling loads to size a water-side economizer?

Answer

No. The design cooling load calculations must be rerun with the outdoor air temperature set to 50°Fdb/45°Fwb. The specified tower, as well as cooling coils and other devices, must be checked to determine if it has adequate capacity at this lower load and wet-bulb condition.

Example 4-33

Question

Will a strainer cycle water-side economizer meet the prescriptive economizer requirements? (Refer to Figure 4-4.)

Answer

No. It cannot be integrated to cool simultaneously with the chillers.

Example 4-34

Question

Does a 12 ton packaged AC unit in climate zone 10 need an economizer?

Answer

Yes. However that requirement can be waived per exception 5 to §144(e)1 if the AC unit's efficiency is greater than or equal to an EER of 11.9. Refer to Standards Table 144-A.

Supply Pressure Controls for VAV Systems

§144(c)2

VAV systems with motors > = 10 hp are required to have either:

- A mechanical or electrical variable speed drive fan motor;
- Vane axial fan with variable pitch blades; or

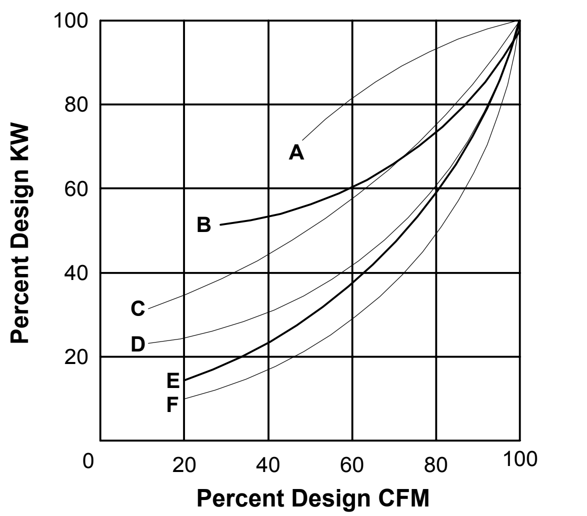
- Include controls that limit the fan motor demand to no more than 30% of design wattage at 50% design air volume when the static pressure set point is one-third of total design static pressure.

Actual fan part load performance, available from the fan manufacturer, should be used to test for compliance with item 3) above. Figure 4-18 shows typical performance curves for different types of fans. As can be seen, both airfoil fans and backward inclined fans using either discharge dampers or inlet vanes consume more than 30% power at 50% flow when static pressure set point is one-third of total design static pressure using certified manufacturer's test data. These fans will not normally comply with these requirements unless a variable speed drive is used.

VAV fan systems that don't have DDC to the zone level are required to have the static pressure sensor located in a position such that the control setpoint is <=1/3 of the design static pressure of the fan. For systems without static pressure reset the further the sensor is from the fan the more energy will be saved. For systems with multiple duct branches in the distribution you must provide separate sensors in each branch and control the fan to satisfy the sensor with the greatest demand. When locating sensors, care should be taken to have at least one sensor between the fan and all operable dampers (e.g. at the bottom of a supply shaft riser before the floor fire/smoke damper) to prevent loss of fan static pressure control.

For systems with DDC to the zone level the sensor may be anywhere in the distribution system and the setpoint must be reset by the zone demand. Typically this is done by either controlling so that one VAV box damper is 95% open or using a "trim and respond" algorithm to continually reduce the pressure until one or more zones indicate that they are unable to maintain airflow rate setpoints.

Reset of supply pressure by demand not only saves energy but it also protects fans from operation in surge at low loads. Chapter 8, Acceptance Requirements, describes mandated acceptance test requirements for VAV system fan control



A. Air foil or backward inclined centrifugal fan with discharge dampers
B. Air foil centrifugal fan with inlet vanes
C. Forward curved centrifugal fan with discharge dampers or riding curve
D. Forward curved centrifugal fan with inlet vanes
E. Vane-axial fan with variable pitch blades
F. Any fan with variable speed drive (mechanical drives will be slightly less efficient)

Figure 4-18 – VAV Fan Performance Curve

Supply-Air Temperature Reset Control

§144(f)

Mechanical space-conditioning systems supplying heated or cooled air to multiple zones must include controls that automatically reset the supply-air temperature in response to representative building loads, or to outdoor air temperature. The controls must be capable of resetting the supply-air temperature by at least 25% of the difference between the design supply-air temperature and the design room air temperature.

For example, if the design supply temperature is 55°F and the design room temperature is 75°F, then the difference is 20°F, and 25% is 5°F. Therefore, the controls must be capable of resetting the supply temperature from 55°F to 60°F.

Air distribution zones that are likely to have constant loads, such as interior zones, shall have airflow rates designed to meet the load at the fully reset temperature. Otherwise, these zones may prevent the controls from fully resetting the temperature, or will unnecessarily limit the hours when the reset can be used.

Supply air reset is required for VAV reheat systems that don't use variable speed drives to control the supply fans. Although it is not required on VAV systems that have VSDs it is generally a good idea to provide it. With DDC controls the recommended control sequence is to lead with supply temperature setpoint reset in cool weather where reheat might dominate the equation and to keep the chillers off as long as possible, then return to a fixed low setpoint in warmer weather when the chillers are likely to be on. During reset, employ a demand-based control that uses the warmest supply air temperature that satisfies all of the zones in cooling.

This sequence is described as follows: during occupied mode, the setpoint is reset from T-min (53°F) when the outdoor air temperature is 70°F and above, proportionally up to T-max when the outdoor air temperature is 65°F and below. T-max shall range from 55°F to 65°F and shall be the output of a slow reverse-acting proportional-integral (PI) loop that maintains the cooling loop of the zone served by the system with the highest cooling loop at a setpoint of 90%. See Figure 4-19.

Supply temperature reset is also required for constant volume systems with reheat justified on the basis of special zone pressurization relationships or cross-contamination control needs.

Supply-air temperature reset is not required when:

- The zone(s) must have specific humidity levels required to meet process needs; or
- Where it can be demonstrated to the satisfaction of the enforcement agency that supply air reset would increase overall building energy use; or
- The space-conditioning zone has controls that prevent reheating and recooling and simultaneously provide heating and cooling to the same zone; or
- Seventy five percent of the energy for reheating is from *site-recovered* or *site solar* energy source; or
- The system is variable air volume and the supply fan is provided with a variable speed drive; or
- The zone has a peak supply air quantity of 300 cfm or less.

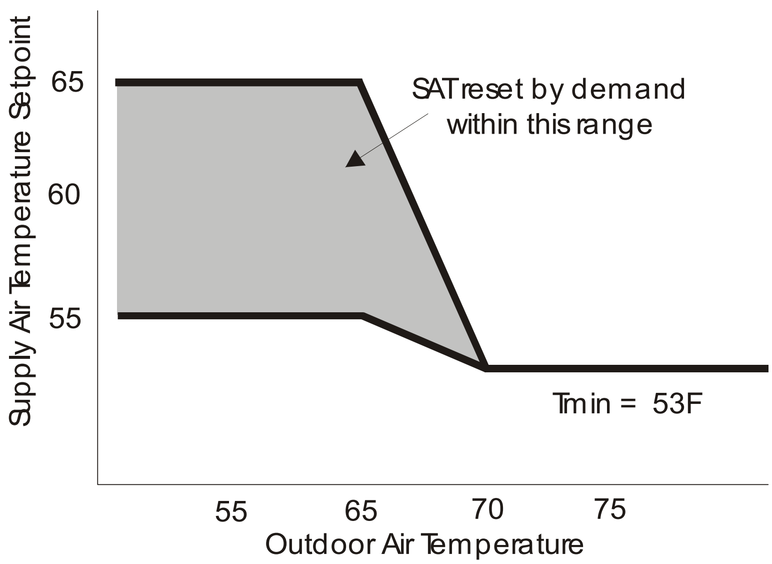


Figure 4-19 – Energy Efficient Supply Air Temperature Reset Control for VAV Systems
Recommended Supply Air Temperature Reset Method

Heat Rejection Fan Control

(§144(h)2)

The fans on cooling towers, closed-circuit fluid coolers, air-cooled condensers and evaporative condensers are required to have speed control except as follows:

- Fans powered by motors smaller than 7.5 hp
- Heat rejection devices included as an integral part of the equipment listed in the Standards Tables 112-A through 112-E. This includes unitary air-conditioners, unitary heat pumps, packaged chillers and packaged terminal heat pumps.
- Condenser fans serving multiple refrigerant circuits or flooded condensers.
- Up to 1/3 of the fans on a condenser or tower with multiple fans where the lead fans comply with the speed control requirement.

Where applicable, two-speed motors, pony motors or variable speed drives can be used to comply with this requirement.

Example 4-35

Question

A chilled water plant has a three-cell tower with 10 hp motors on each cell. Are speed controls required?

Answer

Yes. At minimum the designer must provide 2-speed motors, pony motors or variable speed drives on two of the three fans for this tower.

Hydronic System Controls

§144(j)

The 2005 Standards features new requirements for hydronic system controls. These include:

- Design of systems for variable flow [§144(j)1].
- Chiller and boiler Isolation [§144(j)2 and 3].
- Chilled and hot water reset [§144(j)4].
- Isolation valves for water-loop heat pump systems [§144(j)5].
- VSDs for pumps serving variable flow systems [§144(j)6].

Each of these is described in the paragraphs that follow and Chapter 8, Acceptance Requirements, describes mandated acceptance test requirements for hydronic system controls.

Design of Systems for Variable Flow §144(j)1

Hot water and chilled water systems that have more than 3 control valves are required to be designed for variable flow. Aside from chiller plants serving ≤ 3 air handling units this covers most systems. Variable flow is provided by using 2-way control valves. The Standards only requires that flow is reduced to the greater of 50% design flow or the minimum flow required by the equipment manufacturer for operation of the central plant equipment.

It should be noted that the primary loop on a primary/secondary or primary/secondary/tertiary system can be designed for constant flow even if the secondary or tertiary loop serves more than 3 control valves. This is allowed because the primary loop does not directly serve any coil control valves. However the secondary (and tertiary loops) of these systems must be designed for variable flow if they have 4 or more control valves.

The flow limitations are provided for primary-only variable flow chilled water systems where a minimum flow is typically required to keep a chiller on-line. In these systems minimum flow can be provided with either a bypass with a control valve or some 3-way valves to ensure minimum flow at all times. The system with a bypass valve is more efficient as it only provides bypass when absolutely required to keep the plant on line.

For hot water systems application of slant-tube or bent tube boilers will provide the greatest flow turndown. Typically copper fin tube boilers require a higher minimum flow.

Chiller and Boiler Isolation(§144(j)2 and 3

Plants with multiple chillers or boilers are required to provide either isolation valves or dedicated pumps and check valves to ensure that flow will only go through the chillers or boilers that are staged on. Chillers that are piped in series for the purpose of increased temperature differential shall be considered as one chiller.

Chilled and Hot Water Reset §144(j)4

Similar to the requirements for supply air temperature reset, chilled and hot water systems that have a design capacity > 500,000 Btu/h are required to provide controls to reset the hot or cold water temperature setpoints as a function of building loads or the outdoor air temperature. This reset can be achieved either using a direct indication of demand (usually cooling or heating valve position) or an indirect indication of demand (typically outdoor air temperature). On systems with DDC controls reset using valve position is recommended.

There is an exception to this requirement for hydronic systems that are designed for variable flow complying with §144(j)1.

Isolation Valves for Water-Loop Heat Pump Systems §144(j)5

Water-loop heat pump systems that have a design circulation pump brake horsepower >5 bhp are required to be provided with 2-way isolation valves that close whenever the compressor is off. These systems are also required to be provided with the variable speed drives and pressure controls described in the following section.

Although this is not required on central tenant condenser water systems (for water-cooled AC units and HPs) it is a good idea to provide the 2-way isolation valves on these systems as well. In addition to providing pump energy savings these 2-way valves can double as head-pressure control valves to allow aggressive condenser water reset for energy savings in chilled water plants that are also cooled by the towers. .

VSDs for Pumps Serving Variable Flow Systems §144(j)6

Pumps on variable flow systems that have a design circulation pump brake horsepower > 5 bhp are required to have variable speed drives that are controlled to provide pressure to either the most remote heat exchanger or the heat exchanger requiring the most pressure. This includes chilled water systems, condenser water systems serving water-cooled air conditioning (AC) loads and water-loop heat pump systems.

Exceptions are provided for hot-water systems and condenser water systems that only serve water-cooled chillers. The hot water systems are exempted because the heat from the added pumping energy of the pump riding the curve provides a beneficial heat that reduces the boiler use. This reduces the benefit from the reduced pumping energy.

4.5.3 Acceptance Requirements

There are a number of acceptance requirements related to control systems. These include:

- Automatic time switch control devices.
- Constant volume package unit.
- Air-side economizers.
- VAV supply fan controls.
- Hydronic system controls.

These tests are described in Chapter 8, Acceptance Requirements, as well as the ACM Manual Appendices NG and NJ.

4.6 HVAC System Requirements

The HVAC system requirements are all prescriptive requirements and may be modified in the whole building performance process. There are no mandatory measures or acceptance requirements.

4.6.1 Sizing and Equipment Selection

§144(a)

The Standards require that mechanical heating and cooling equipment (including electric heaters and boilers) be the smallest size available, within the available options of the desired equipment line, that meets the design heating and cooling loads of the building or spaces being served. Depending on the equipment, oversizing can be either a penalty or benefit to energy usage. For vapor compression equipment, gross oversizing can drastically increase the energy usage and in some cases cause premature failure from short cycling of compressors. Boilers and water-heaters generally suffer lower efficiencies and higher standby losses if they are oversized. On the other hand, cooling towers, cooling coils, and variable speed driven cooling tower fans can actually improve in efficiency if oversized. Oversized distribution ductwork and piping can reduce system pressure losses and reduce fan and pump energy.

When equipment is offered in size increments, such that one size is too small and the next is too large, the larger size may be selected.

Packaged HVAC equipment may serve a space having substantially different heating and cooling loads. The unit size should be selected on the larger of the loads, based on either capacity or airflow. The capacity for the other load should be selected as required to meet the load, or if very small, should be the smallest capacity available in the selected unit. For example, packaged air-conditioning units with gas heat are usually sized on the basis of cooling loads. The furnace is sized on the basis of airflow, and is almost always larger than the design heating load.

Equipment may be oversized provided one or more of the following conditions are met:

- It can be demonstrated to the satisfaction of the enforcing agency that oversizing will not increase building source energy use; or
- Oversizing is the result of standby equipment that will operate only when the primary equipment is not operating. Controls must be provided that prevent the standby equipment from operating simultaneously with the primary equipment; or
- Multiple units of the same equipment type are used, each having a capacity less than the design load, but in combination having a capacity greater than the design load. Controls must be provided to sequence or otherwise optimally control the operation of each unit based on load.

4.6.2 Load Calculations

§144(b)

For the purposes of sizing HVAC equipment, the designer shall use all of the following criteria for load calculations:

- The heating and cooling system design loads must be calculated in accordance with the procedures described in the ASHRAE Handbook, 2001, Fundamentals Volume. Other load calculation methods, e.g. ACCA, SMACNA, etc., are acceptable provided that the method is ASHRAE-based. When submitting load calculations of this type, the designer must accompany the load calculations with a written affidavit certifying that the method used is ASHRAE-based. If the designer is unclear as to whether or not the calculation method is ASHRAE-based, the vendor or organization providing the calculation method should be contacted to verify that the method is derived from ASHRAE.

- Indoor design conditions of temperature and relative humidity for general comfort applications are not explicitly defined. Designers are allowed to use any temperature conditions within the “comfort envelope” defined by ANSI/ASHRAE 55-1992 or Chapter 8 of the ASHRAE Handbook, 2003, Fundamentals Volume. Winter humidification or summer dehumidification is not required.
- Outdoor design conditions shall be selected from Joint Appendix II, which is based on data from the ASHRAE Climatic Data for Region X, for the following design conditions:
- Heating design temperatures shall be no lower than the temperature listed in the Heating Winter Median of Extremes value.
- Cooling design temperatures shall be no greater than the 0.5% Cooling Dry Bulb and Mean Coincident Wet Bulb values.
- Outdoor Air Ventilation loads must be calculated using the ventilation rates required in §121. At minimum, the ventilation rate will be 15 cfm/person or 0.15 cfm/ft², whichever is greater.
- Envelope heating and cooling loads must be calculated using envelope characteristics including square footage, thermal conductance, solar heat gain coefficient and air leakage, consistent with the proposed design.
- Lighting loads shall be based on actual design lighting levels or power densities consistent with §146.
- People sensible and latent gains must be based on the expected occupant density of the building and occupant activities. If ventilation requirements are based on a cfm/person basis, then people loads must be based on the same number of people as ventilation. Sensible and latent gains must be selected for the expected activities as listed in ASHRAE Handbook, 2001, Fundamentals Volume, Chapter 29, Table 1.
- Loads caused by a process shall be based on actual information (not speculative) on the intended use of the building.
- Miscellaneous equipment loads include such things as duct losses, process loads and infiltration and shall be calculated using design data compiled from one or more of the following sources:
- Actual information based on the intended use of the building; or
- Published data from manufacturer’s technical publications and from technical societies, such as the ASHRAE Handbook, 2003 HVAC Applications Volume; or
- Other data based on the designer’s experience of expected loads and occupancy patterns.
- Internal heat gains may be ignored for heating load calculations.

A safety factor of up to 10% may be applied to design loads to account for unexpected loads or changes in space usage.

- Other loads such as warm-up or cool-down shall be calculated using one of the following methods:

  A method using principles based on the heat capacity of the building and its contents, the degree of setback, and desired recovery time; or

  The steady state design loads may be increased by no more than 30% for heating and 10% for cooling. The steady state load may include a safety factor of up to 10% as discussed above in Item 11.

The combination of safety factor and other loads allows design cooling loads to be increased by up to 21% (1.10 safety x 1.10 other), and heating loads by up to 43% (1.10 safety x 1.30 other).

Example 4-36

Question

Do the sizing requirements restrict the size of duct work, coils, filter banks, etc. in a built-up system?

Answer

No. The intent of the Standards is to limit the size of equipment, which if oversized will consume more energy on an annual basis. Coils with larger face areas will usually have lower pressure drops than otherwise, and may also allow the chilled water temperature to be higher, both of which may result in a decrease in energy usage. Larger filter banks will also usually save energy. Larger duct work will have lower static pressure losses, which may save energy, depending on the duct's location, length, and degree of insulation.

Oversizing fans, on the other hand, may or may not improve energy performance. An oversized airfoil fan with inlet vanes will not usually save energy, as the part load characteristics of this device are poor. But the same fan with a variable frequency drive may save energy. Controls are also an important part of any system design.

The relationship between various energy consuming components may be complex, and is left to the designer's professional judgment. Note however, that when components are oversized, it must be demonstrated to the satisfaction of the enforcement agency that energy usage will not increase.

4.6.3 Fan Power Consumption

§144(c)

Maximum fan power is regulated in individual fan systems where the total power of the supply, return and exhaust fans within the *fan system* exceed 25 horsepower at design conditions (see Section 4.10 for definitions). A system consists of only the components that must function together to deliver air to a given area; fans that can operate independently of each other comprise separate systems. Included are all fans associated with moving air from a given space-conditioning *system* to the conditioned spaces and back to the source, or to exhaust it to the outdoors.

The 25 horsepower total criteria apply to:

- All supply and return fans within the space-conditioning system that operate at peak load conditions.
- All exhaust fans at the system level that operate at peak load conditions. Exhaust fans associated with economizers are not counted provided they do not operate at peak conditions.
- Fan-powered VAV boxes, if these fans run during the cooling peak. This is always the case for fans in series type boxes. Fans in parallel boxes may be ignored if they are controlled to operate only when zone heating is required, and are normally off during the cooling peak.
- Elevator equipment room exhausts, or other exhausts that draw air from a conditioned space, through an otherwise unconditioned space, to the outdoors.
- Computer room units.

The criteria are applied individually to each space-conditioning system. In buildings having multiple space-conditioning systems, the criteria applies only to the systems having fans whose total demand exceeds 25 horsepower.

Not included are fans not directly associated with moving conditioned air to or from the space-conditioning system, or fans associated with a process within the building.

For the purposes of the 25 horsepower criteria, horsepower is the brake horsepower as listed by the manufacturer for the design conditions, plus any losses associated with the drive, including belt losses or variable frequency drive losses. If the brake horsepower is not known, then the nameplate horsepower should be used.

If drive losses are not known, the designer may assume that direct drive efficiencies are 1.0, and belt drives are 0.97. Variable speed drive efficiency should be taken from the manufacturer's literature; if it includes a belt drive, it should be multiplied by 0.97.

Total fan horsepower need not include the additional power demand caused solely by air treatment or filtering systems with final pressure drops of more than 1 in. water gauge (w.g.). It is assumed that conventional systems may have filter pressure drops as high as 1 in. w.g.; therefore only the horsepower associated with the portion of the pressure drop exceeding 1 in., or fan system power caused solely by process loads, may be excluded.

For buildings whose systems exceed the 25 horsepower criteria, the total space-conditioning system power requirements are:

1. Constant volume fan systems. The total fan power index at design conditions of each fan system with total horsepower over 25 horsepower shall not exceed 0.8 watts per cfm of supply air.
2. Variable air volume (VAV) systems.

A. The total fan power index at design conditions of each fan system with total horsepower over 25 horsepower shall not exceed 1.25 watts per cfm of supply air; and

B. Individual VAV fans with motors 10 horsepower or larger shall meet one of the following:

i. The fan motor shall be driven by a mechanical or electrical variable speed drive.

ii. The fan shall be a vane-axial fan with variable pitch blades.

iii. For prescriptive compliance, the fan motor shall include controls that limit the fan motor demand to no more than 30% of the total design wattage at 50% of design air volume when static pressure set point equals 1/3 of the total design static pressure, based on certified manufacturer's test data.

C. Static Pressure Sensor Location. Static pressure sensors used to control variable air volume fans shall be placed in a position such that the controller set point is no greater than one-third the total design fan static pressure, except for systems with zone reset control complying with 144 (c) 2 D. If this results in the sensor being located downstream of major duct splits, multiple sensors shall be installed in each major branch with fan capacity controlled to satisfy the sensor furthest below its setpoint.

D. Set Point Reset. For systems with direct digital control of individual zone boxes reporting to the central control panel, static pressure set point shall be reset based on the zone requiring the most pressure; i.e., the set point is reset lower until one zone damper is nearly wide open.

3. Air-treatment or filtering systems. For systems with air-treatment or filtering systems, calculate the adjusted fan power index using equation 144-A:

EQUATION 144-A ADJUSTED FAN POWER INDEX

Adjusted fan power index = Fan power index x Fan Adjustment

Fan Adjustment = ·□1-(SPa - 1)/ SPf.

WHERE:

SPa = Air pressure drop across the air-treatment or filtering system.

SPf= Total pressure drop across the fan.

4. Fan motors of series fan-powered terminal units. Fan motors of series fan-powered terminal units 1 horsepower or less in shall

be electronically-commutated motors or shall have a minimum motor efficiency of 70% when rated in accordance with NEMA Standard MG 1-1998 Rev. 2 at full load rating conditions.

The total system power demand is based on brake horsepower at design static and cfm, and includes drive losses and motor efficiency. If the motor efficiency is not known, values from ACM Manual Appendix NC may be used.

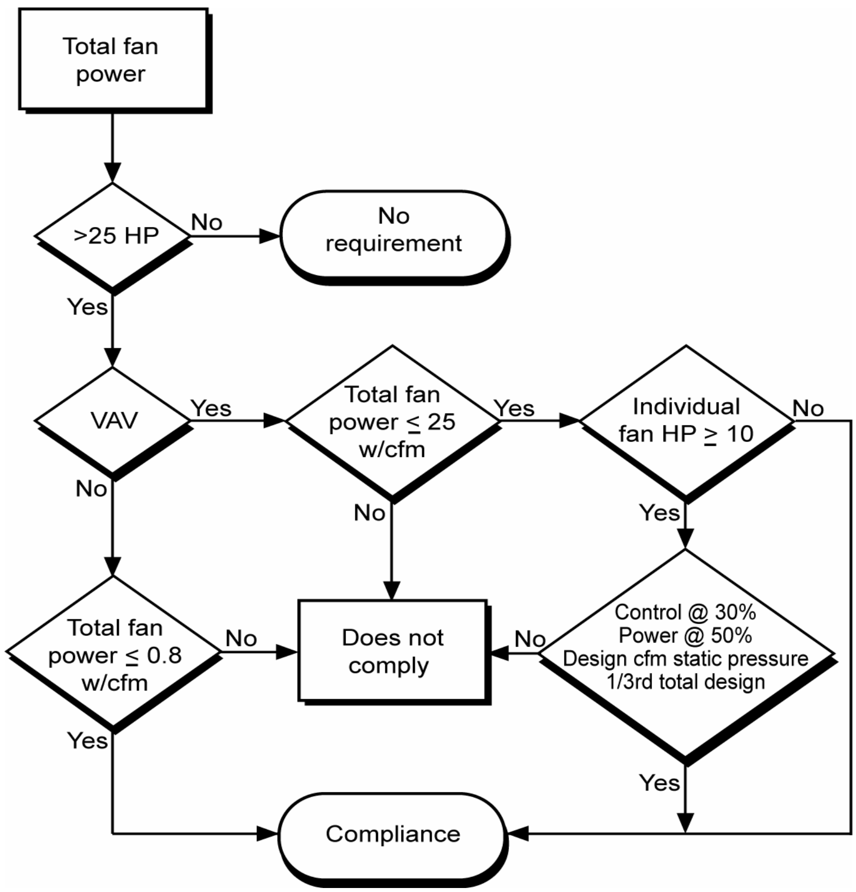
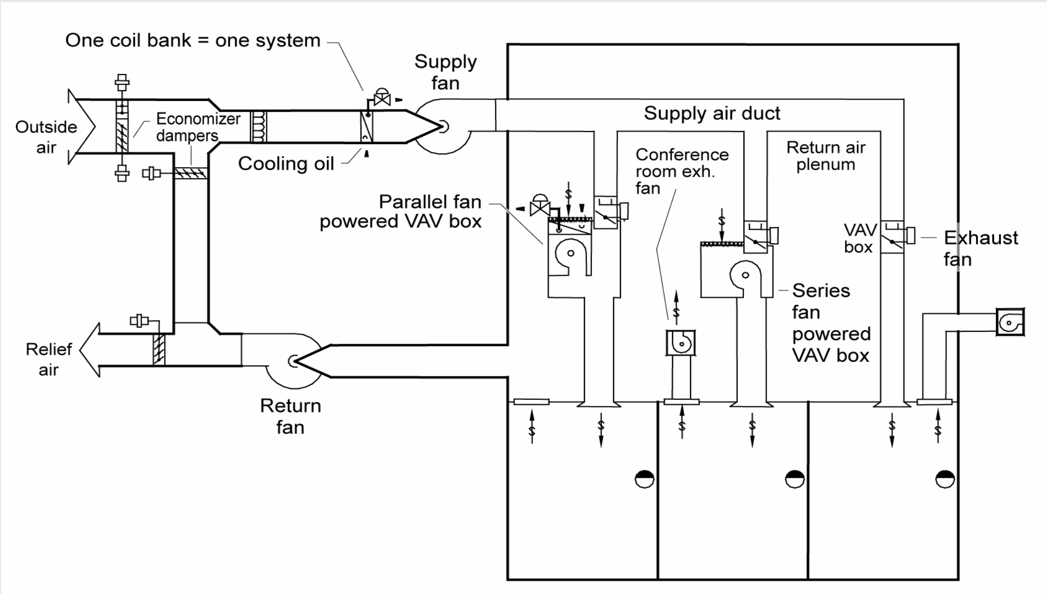


Figure 4-20 – Fan Power Flowchart

Example 4-37

Question

In the system depicted below, which fans are included in the fan power criteria?



Answer

The fans included are those that operate during the design cooling load. These include the supply fan, the return fan, the series fan-powered VAV box(es), the general exhaust fan, and conference room exhaust fans other than those that are manually controlled. The parallel fan-powered VAV box(es) are not included as those fans only operate during a call for zone heating.

Example 4-38

Question

If a building has five zones with 15,000 cfm air handlers that are served by a common central plant, and each air handler has a 15 HP supply fan, does the 25 HP limit apply?

Answer

No. Each air handler, while served by a common central plant, is a separate fan system. Since the demand of each air handler is only 15 HP, the 25 HP criteria does not apply.

Example 4-39

Question

The space-conditioning system in a laboratory has a 30% filter with a design pressure drop at change out of 0.5 in. w.g., and an 80% filter with a design pressure drop of 1.2 in. w.g. The design total static pressure of the fan is 5.0 inch w.g. What percentage of the power may be excluded from the W/cfm calculation?

Answer

The total filter drop at change out (final pressure drop) is 0.5 in. + 1.2 in. = 1.7 in. w.g. The amount that may be excluded is 1.7 in.-1.0 in. = 0.7 in. w.g. The percentage of the horsepower that may be excluded is 0.7 in./5.0 in. = 14%

If the supply fan requires 45 brake horsepower, the adjusted horsepower of the supply fan in the W/cfm calculation is

45 BHP x (1 - 14%) = 38.7 BHP

The horsepower of any associated return or exhaust fan is not adjusted by this factor, as the filters have no impact on these fans.

Example 4-40

Question

What is the maximum allowed power consumption for the fans in a VAV bypass system?

Answer

A VAV bypass, while variable volume at the zone level, is constant volume at the fan level. If the total fan power demand of this system exceeds 25 HP, then the fan power may not exceed 0.8 W/cfm.

Example 4-41

Question

What is the power consumption of a 20,000 cfm VAV system having an 18 BHP supply fan, a 5 BHP return fan, a 3 BHP economizer relief fan, a 2 HP outside air ventilation fan and a 1 HP toilet exhaust fan? Note that the exhaust and outside air ventilation fans are direct drive and listed in HP not BHP. The supply and return fans are controlled with variable frequency drives having an efficiency of 96%.

Answer

The economizer fan is excluded provided it does not run at the time of the cooling peak.

Power consumption is then based on the supply; return, outdoor and toilet exhaust fans. The ventilation fan is direct drive so its efficiency is 1.0. The supply and return fans have default drive efficiencies of 0.97. From Tables NC-1 and NC-2 from ACM Manual Appendix NC, the assumed efficiencies of the motors are 91.7% and 87.5% for a 25 and 7.5 HP 4-pole motor respectively. Fan power demand in units of horsepower must first be calculated to determine whether the requirements apply:

a. 18 BHP / (0.97 x 0.917 x 0.96) = 21.1.0 HP

b. 5 BHP / (0.97 x 0.875 x 0.96) = 6.1 HP

Total power consumption, adjusted for efficiencies, is calculated as:

21.1.0 HP + 6.1 HP + 2 HP + 1 HP = 30.2 HP

Since this is larger than 25 HP, the limitations apply. W/cfm is calculated as:

30.2 HP x 746 W/cfm/20,000 cfm = 1.13 W/cfm

The system complies because power consumption is below 1.25 Wcfm. Note that, while this system has variable frequency drives, they are only required by the Standards for the 18 BHP fan since each other fan is less than 10 HP.

4.6.4 ECM Motors for Series Style VAV Boxes

§144(c)4

Series style fan powered boxes with motors ≤ 1 hp are required to have either electrically commuted motors (ECM) or shall have a minimum motor efficiency of 70% when rated in accordance with NEMA Standard MG 1-1998 Rev. 2 at full load rating conditions. This is a new requirement in 2005.

4.6.5 Electric-Resistance Heating

§144(g), 149

The Standards strongly discourage the use of electric-resistance space heat. Electric-resistance space heat is not allowed in the prescriptive approach except where:

- Site-recovered or site-solar energy provides at least 60% of the annual heating energy requirements; or
- A heat pump is supplemented by an electric-resistance heating system, and the heating capacity of the heat pump is more than 75% of the design heating load at the design outdoor temperature, determined in accordance with the Standards; or
- The total capacity of all electric-resistance heating systems serving the entire building is less than 10% of the total design output capacity of all heating equipment serving the entire building; or
- The total capacity of all electric-resistance heating systems serving the building, excluding those that supplement a heat pump, is no more than 3 kW; or
- An electric-resistance heating system serves an entire building that:
- Is not a high-rise residential or hotel/motel building; and
- Has a conditioned floor area no greater than 5,000 ft^2; and
- Has no mechanical cooling; and
- Is in an area where natural gas is not currently available and an extension of a natural gas system is impractical, as determined by the natural gas utility.
- In alterations where the existing mechanical systems use electric reheat (when adding variable air volume boxes) added capacity cannot exceed 20% of the existing installed electric capacity, under any one permit application.
- In an addition where the existing variable air volume system with electric reheat is being expanded the added capacity cannot exceed 50% of the existing installed electric reheat capacity under any one permit.

The Standards in effect allow a small amount of electric-resistance heat to be used for local space heating or reheating (provided reheat is in accordance with these regulations).

Example 4-42

Question

If a heat pump is used to condition a building having a design heating load of 100,000 Btu/h at 35°F, what are the sizing requirements for the compressor and heating coils?

Answer

The compressor must be sized to provide at least 75% of the heating load at the design heating conditions, or 75,000 Btu/h at 35°F. The Standards do not address the size of the resistance heating coils. Normally, they will be sized based on heating requirements during defrost.

4.6.6 Cooling Tower Flow Turndown

§ 144(h)3

The Standards require that open cooling towers with multiple condenser water pumps be designed so that all cells can be run in parallel with the larger of

- The flow that's produced by the smallest pump, or
- Thirty three percent of the design flow for the cell.

Note that in a large plant at low load operation you would typically run less than all of the cells at once. This is allowed in the standard.

Cooling towers are very efficient at unloading (the fan energy drops off as the cube of the airflow). It is always more efficient to run the water through as many cells as possible; 2 fans at ½ speed use less than 1/3 of the energy of 1 fan at full speed for the same load. Unfortunately there is a limitation with flow on towers, the flow must be sufficient to provide full coverage of the fill. If the nozzles don't fully wet the fill, air will go through the dry spots providing no cooling benefit and cause the water at the edge of the dry spot to flash evaporate depositing dissolved solids on the fill.

Luckily the cooling tower manufacturers do offer low-flow nozzles (and weirs on basin type towers) to provide better flow turndown. This typically only costs $100 to $150 per tower cell. As it can eliminate the need for a tower isolation control point this provides energy savings at a reduced first cost.

Example 4-43

Question

If a large central plant has five equally sized chillers and five equally sized cooling tower cells do all of the cooling tower cells need to operate when only one chiller is on-line?

Answer

No you would probably only run three cells with one chiller. The cooling tower cells must be designed to run at 33% of their nominal design flow. With two to five chillers running you would run all of the cells of cooling tower. With only one chiller running you would run three cells. In each case you would need to keep the tower flow above the minimum that it was designed for.

4.6.7 Centrifugal Fan Limitation

§ 144(h)4

Open cooling towers with a combined rated capacity of 900 gpm and greater at 95°F condenser water return, 85°F condenser water supply and 75°F outdoor wet-bulb temperature are prohibited to use centrifugal fans. The 95°F condenser water return, 85°F condenser water supply and 75°F outdoor wet-bulb temperature are test conditions for determining the rated flow capacity in gpm. Centrifugal fans use approximately twice the energy as propeller fans for the same duty. There are a couple of exceptions to this requirement.

- Cooling towers that are ducted (inlet or discharge) or have an external sound trap that requires external static pressure capability.
- Cooling towers that meet the energy efficiency requirement for propeller fan towers in §112, Standards Table 112-G.

Centrifugal fans may be used on closed circuit fluid coolers.

As with all prescriptive requirements centrifugal fan cooling towers may be used when complying with the performance method. The budget building will be modeled using propeller towers.

4.6.8 Air Cooled Chillers

§144(i)

New central cooling plants and cooling plant expansions that are greater than or equal to 300 tons in installed capacity will be limited on the use of air-cooled chillers. For plant expansions the 300 ton trigger applies only to the newly installed equipment (exception to §149 (b) 1 C). Above this size threshold, air cooled chillers can be provided for ≤ 100 tons of capacity.

In the studies provided to support this requirement, air cooled chillers always provided a higher life-cycle cost than water cooled chillers even accounting for the water and chemical treatment costs.

There are a few exceptions to this requirement:

- Where the designer demonstrates to the authority having jurisdiction that the water quality at the building site fails to meet manufacturer’s specifications for the use of water-cooled equipment.
- Plants serving chilled or ice thermal energy storage systems.
- Air cooled chillers with minimum efficiencies approved by the Commission pursuant to §10-109 (d).

The first exception recognizes that some parts of the State have exceptionally high quantities of dissolved solids that could foul systems or cause excessive chemical treatment or blow down.

The second exception addresses the fact that air-cooled chillers can operate very efficiently at low ambient air temperatures. Since TES systems operate for long hours at night, these systems may be as efficient as a water-cooled plant.

Note that the chiller must be provided with head pressure controls to achieve these savings.

The third exception was provided in the event that an exceptionally high efficiency air cooled chiller was developed. None of the high-efficiency air-cooled chillers currently evaluated are as efficient as a water-cooled systems using the lowest chiller efficiency allowed by §112.

4.6.9 Historic Buildings

Exception 1 to §100(a) states that qualified historic buildings, as defined in the California Historical Building Code (Title 24, Part 8 or California Building Code, Title 24, Part 2, Volume I, Chapter 34, Division II) are not covered by the Standards. However, non-historical components of the buildings, such as new or replacement mechanical, plumbing, and electrical (including lighting) equipment, additions and alterations to historic buildings, and new appliances in historic buildings may need to comply with Building Energy Efficiency Standards and Appliance Standards, as well as other codes. For more information about energy compliance requirements for Historic Buildings, see Section 1.7.1, Building Types Covered, in Chapter 1, the Overview of this manual.

4.7 Service Water Heating

All of the requirements for service hot water are mandatory measures, except for high-rise residential, which must comply with the low-rise residential standards (see Section 4.7.4). There are no acceptance requirements for water heating systems or equipment.

4.7.1 Service Water Systems

Efficiency and Control

§113(a)

Any service water heating equipment must have integral automatic temperature controls that allow the temperature to be adjusted from the lowest to the highest allowed temperature settings for the intended use as listed in Table 2, Chapter 49 of the 2003 ASHRAE Handbook, HVAC Applications Volume.

Water heating systems in high-rise residential buildings must meet the energy budget requirements of the Residential Standards. Service water heaters installed in residential occupancies need not meet the temperature control requirement of §113(a)1.

Multiple Temperature Usage

§113(c)1

On systems that have a total capacity greater than 167,000 Btu/h, outlets requiring higher than service water temperatures as listed in the 2003 ASHRAE Handbook, HVAC Applications Volume shall have separate remote heaters, heat exchangers, or boosters to supply the outlet with the higher temperature. This requires the primary water heating system to supply water at the lowest temperature required by any of the demands served for service water heating. All other demands requiring higher temperatures should be served by separate systems, or by boosters that raise the temperature of the primary supply.

Circulating Systems

§113(c)2

Circulating service water systems must include a control capable of automatically turning off the circulating pump when hot water is not required. Such controls include automatic time switches, interlocks with HVAC time switches, occupancy sensors, and other controls that accomplish the intended purpose. Since residential occupancies have different supply requirements, a system serving a single dwelling unit does not have to meet the requirements of §113(c)2.

Public Lavatories

§113(c)3

Lavatories in public restrooms must have controls that limit the water supply temperature to 110°F. Where a service water heater supplies only restrooms, the heater thermostat may be set to no greater than 110°F to satisfy this requirement; otherwise controls such as automatic mixing valves must be installed.

Storage Tank Insulation

§113(c)4

Unfired water heater storage tanks and backup tanks for solar water heating systems must have:

- External insulation with an installed R-value of at least R-12; or
- Internal and external insulation with a combined R-value of at least R-16; or
- The heat loss of the tank based on an 80 degree F water-air temperature difference shall be less than 6.5 Btu per hour per ft^2. This corresponds to an effective resistance of R-12.3.

Service Water Heaters in State Buildings

§113(c)5

Any newly constructed building constructed by the State shall derive its service water heating from a system that provides at least 60% of the energy needed from site solar energy or recovered energy. This requirement may be waived for buildings where the State Architect determines that such systems are economically or physically infeasible.

4.7.2 Pool and Spa Heating Systems

§114

Pool and spa heating systems must be certified by the manufacturer and listed by the Energy Commission as having:

- An efficiency that complies with the Appliance Efficiency Regulations; and
- An on-off switch mounted on the outside of the heater in a readily accessible location that allows the heater to be shut-off without adjusting the thermostat setting; and
- A permanent, easily readable, and weatherproof plate or card that gives instructions for the energy efficient operation of the pool or spa, and for the proper care of the pool or spa water when a cover is used; and
- No electric resistance heating. The only exceptions are:
- Listed packaged units with fully insulated enclosures and tight fitting covers that are insulated to at least R-6. Listed package units are defined in the National Electric Code and are typically sold as self-contained, UL Listed spas; or
- Pools or spas deriving at least 60% of the annual heating energy from site solar energy or recovered energy.
- No pilot light.

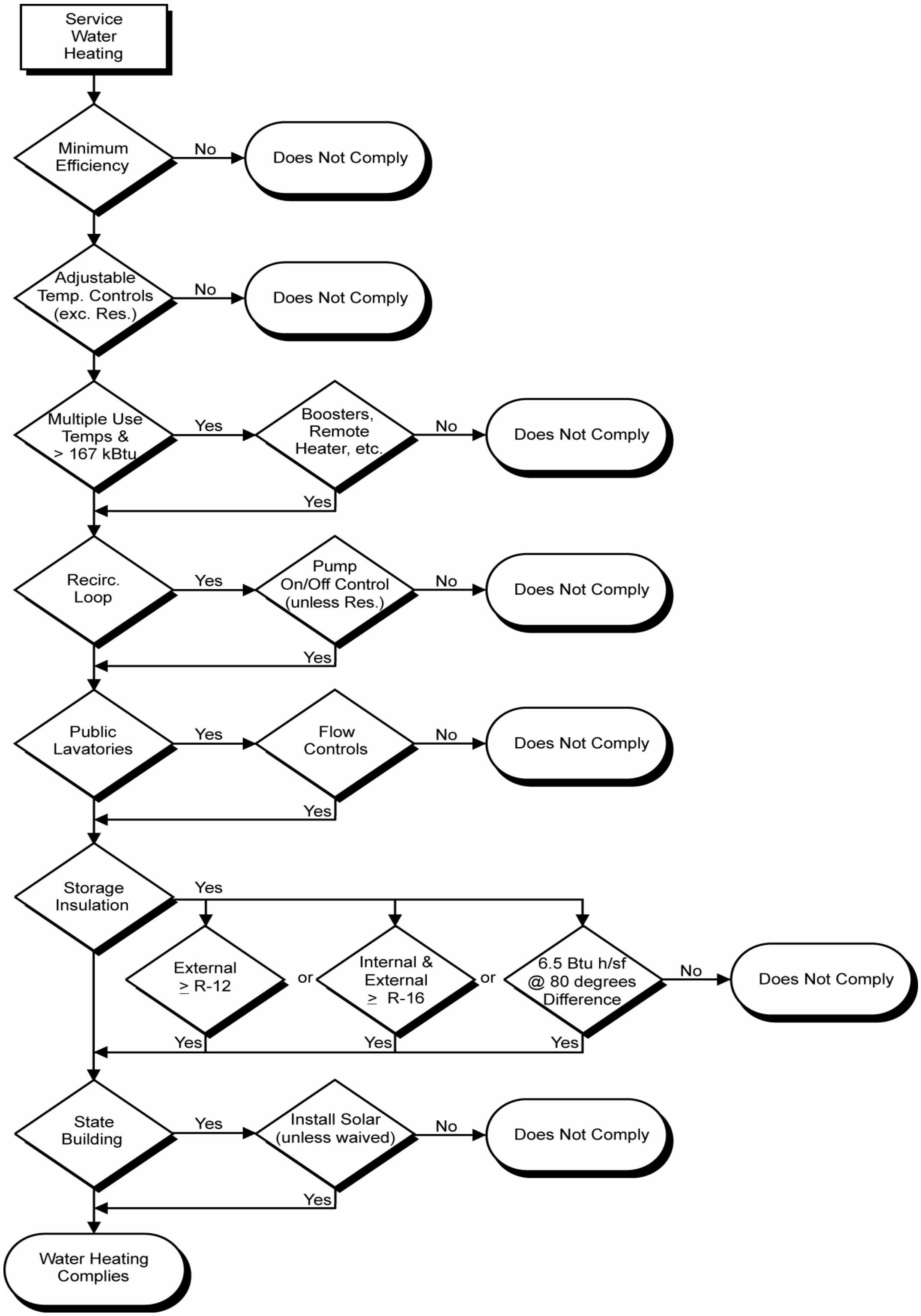


Figure 4-21 – Service Water Heating Flowchart

Pool and spa equipment must be installed with all of the following:

- Solar heater connection - At least 36 inches of pipe between the filter and the heater must be provided to allow for the future addition of solar heating equipment.
- A cover must be provided for outdoor pools and outdoor spas, unless at least 60% of the annual heating energy is provided by site solar energy or recovered energy.
- Directional inlets must be provided for all pools that adequately mix the pool water.
- A time switch must be provided for pools to control the operation of the circulation pump, to allow the pump to be set to run in the off-peak demand period, and for the minimum time necessary to maintain the water in the condition required by applicable public health standards.

A time switch is not required where applicable public health standards require on-peak operation.

4.7.3 Service Water Heating Other Than High-rise Residential

§145

A service water-heating system is considered to comply with the prescriptive requirements when all mandatory requirements are met for occupancies other than high-rise residential. Buildings that have both occupancies other than high-rise residential and high-rise residential must meet the service water heating requirements that apply to each occupancy.

4.7.4 High-rise Residential Service Water Heating

Service water heating systems serving high-rise residential occupancies must comply with §151(f)8. These requirements are described in the Residential Compliance Manual.

4.7.5 Acceptance Requirements

There are no acceptance requirements for service water heating systems.

4.8 Performance Approach

Under the performance approach, the energy use of the building is modeled using a computer program approved by the California Energy Commission. This section presents some basic details on the modeling of building mechanical systems. *Program users and those checking for enforcement should consult the most current version of the user's manuals and associated compliance supplements for specific instructions on the operation of the program.* All computer programs, however, are required to have the same basic modeling capabilities.

More information on how to model the mechanical systems and components are included in Chapter 7, Performance Approach, and in the program vendor's compliance supplement.

4.8.1 Compliance With a Computer Method

Each approved computer method automatically generates an energy budget by calculating the annual time dependent valuation (TDV) energy use of the standard design, a version of the proposed building incorporating all the prescriptive features.

A building complies with the Standards if the predicted TDV energy use of the proposed design is the same or less than the annual energy budget of the standard design. The energy budget includes a space-conditioning budget, lighting budget and water-heating budget.

TDV energy use defines the energy use of a building by converting the calculated energy consumption into TDV energy. Joint Appendix III describes the derivation of the TDV energy multipliers TDV energy multipliers adjust the calculated energy consumption of a building to account for the time dependent energy value of different fuels and inefficiencies in generating and distributing electricity.

The budget for space conditioning of the proposed building design varies according to the following specific characteristics:

- Orientation.
- Space-conditioning system type.
- Occupancy type.
- Climate zone.

Assumptions used by the computer methods in generating the energy budget are explained in the Alternative Calculation Methods Approval Manual and are based on features required for prescriptive compliance.

If any of the following equipment or systems are installed the acceptance tests must be conducted.

- Variable air volume systems.
- Constant volume systems.
- Package systems.
- Air distribution systems.
- Economizers.
- Demand control ventilation systems.
- Variable frequency drive fan systems.
- Hydronic control systems.
- Hydronic pump isolation controls and devices.
- Supply water reset controls.

- Water loop heat pump control.
- Variable frequency drive pump systems.
- System programming.
- Time clocks.

A final occupancy permit can not be granted from the Building Department until all the test have been completed and pass. For more detail see Chapter 8, Acceptance Requirements.

4.8.2 Modeling Mechanical System Components

All alternative calculation methods (state-approved energy compliance software) have the capability to model various types of HVAC systems. In central systems, these modeling features affect the system loads seen by the plant. This is done by calculating the interactions between envelope, mechanical and electrical systems in the building and summarizing the energy required by the mechanical system to maintain space conditions.

For a complete description of how to model mechanical system components, refer to the compliance supplement for the approved computer program being used to demonstrate compliance.

4.9 Additions and Alterations

When heating, cooling or service water heating are provided for an alteration or addition by expanding an existing system, that existing system need not comply with mandatory measures or prescriptive compliance requirements. However, any altered component must meet all applicable mandatory measures and space-conditioning ducts must meet the following.

4.9.1 Mandatory Measures – Additions and Alteration

All additions and alterations must comply with the following mandatory measures:

- §110 – Systems and Equipment—General
- §111 – Mandatory Requirements for Appliances Regulated by the Appliance Efficiency Regulations
- §112 – Mandatory Requirements for Space-Conditioning Equipment
- §113 – Mandatory Requirements for Service Water-Heating Systems and Equipment
- §114 – Mandatory Requirements for Pool and Spa Heating Systems and Equipment
- §115 – Natural Gas Central Furnaces, Cooking Equipment, and Pool and Spa Heaters: Pilot Lights Prohibited

- §121 – Requirements for Ventilation
- §122 – Required Controls for Space-Conditioning Systems
- §123 – Requirements for Pipe Insulation
- §124 – Requirements for Air Distribution System Ducts and Plenums
- §125 – Required Nonresidential Mechanical System Acceptance

For more detailed information about the mandatory measures, refer to following sections of this chapter:

- 4.1.2 Compliance Approaches
- 4.2 Equipment Requirements
- 4.3 Ventilation Requirements
- 4.4 Pipe and Duct Distribution Systems
- 4.5 HVAC System Control Requirements
- 4.7 Service Water Heating

4.9.2 Prescriptive Requirements – Additions

All new additions must comply with the following prescriptive requirements:

- §144 – Prescriptive Requirements for Space Conditioning Systems
- §145 – Prescriptive Requirements for Service Water-Heating Systems

For more detailed information about the prescriptive requirements, refer to following sections of this chapter

- 4.1.2 Compliance Approaches
- 4.2 Equipment Requirements
- 4.5 HVAC System Control Requirements
- 4.6 HVAC System Requirements
- 4.6.5 Electric-Resistance Heating

Performance approach may also be used to demonstrate compliance for new additions. Refer to Chapter 7, Performance Approach, for more details.

Acceptance tests must be conducted on the following equipment or systems when installed in new additions:

- Variable air volume systems.
- Constant volume systems.
- Package systems.
- Air distribution systems.
- Economizers.
- Demand control ventilation systems.

- Variable frequency drive fan systems.
- Hydronic control systems.
- Hydronic pump isolation controls and devices.
- Supply water reset controls.
- Water loop heat pump control.
- Variable frequency drive pump systems.
- System programming.
- Time clocks.

For more detail, see Chapter 8, Acceptance Requirements.

4.9.3 Prescriptive Requirements – Alterations

When new or replacement space-conditioning ducts are installed to serve an existing building, the new ducts shall meet the requirements of §124 (insulation levels, sealing materials and methods etc.).

If the ducts are part of a single zone constant volume system serving less than 5,000 ft^2 and more than 25% of the ducts are outdoors or in unconditioned area including attic spaces and above insulated ceilings [the criteria of §144 (k) 1, 2, and 3], the duct system shall be sealed and tested for air leakage by the contractor. In most nonresidential buildings this requirement will not apply because the roof is insulated so that almost all of the duct length is running through directly or indirectly conditioned space.

If the ducts are in unconditioned space and have to be sealed, they must also be tested to leak no greater than 6% if the entire duct system is new or less than 15% if the duct system is added to a pre-existing duct system. The description of the test method can be found in Section 4.3.8.2 of Appendix NG of the Nonresidential ACM Manual. The air distribution acceptance test associated with this can be found in Appendix NJ 5.1 of the Nonresidential ACM Manual. This and all acceptance tests are described in Chapter 8 of this manual.

If the new ducts form an entirely new duct system directly connected to the air handler, the measured duct leakage shall be less than 6% of fan flow; or

If the new ducts are an extension of an existing duct system, the combined new and existing duct system shall meet one of the following requirements:

- The measured duct leakage shall be less than 15% of fan flow; or
- The duct leakage shall be reduced by more than 60% relative to the leakage prior to the equipment having been replaced and a visual inspection shall demonstrate that all accessible leaks have been sealed; or
- If it is not possible to meet the duct sealing requirements of Subsections a. or b., all accessible leaks shall be sealed and verified through a visual inspection by a certified HERS rater.

EXCEPTION to Section 149 (b) 1 D ii: Existing duct systems that are extended, which are constructed, insulated or sealed with asbestos.

Once the ducts have been sealed and tested to leak less than the above amounts, a HERS rater will be contacted by the contractor to validate the accuracy of the duct sealing measurement on a sample of the systems repaired as described in the Nonresidential ACM Manual.

Similar requirements apply to ducts upon replacement of small (serving less than 5,000 sf) constant volume HVAC units or their components *(including replacement of the air handler, outdoor condensing unit of a split system air conditioner or heat pump, cooling or heating coil, or the furnace heat exchanger).* Again the duct sealing requirements are for those systems where over 25% of the duct area is outdoors or in unconditioned areas including attic spaces and above insulated ceilings.

One can avoid sealing the ducts by insulating the roof and sealing the attic vents as part of a larger remodel, thereby creating a conditioned space within which the ducts are located, and no longer meets the criteria of §144 k. Another alternative to duct sealing is to install a high EER air conditioner that will save as much energy as the duct system is losing though leaks. This trade-off can be calculated using the performance software or by using pre-calculated equipment efficiencies deemed comparable to duct sealing in Table 4-5 in Section 4.4.2.

When a space conditioning system is altered by the installation or replacement of space conditioning equipment (including replacement of the air handler, outdoor condensing unit of a split system air conditioner or heat pump, cooling or heating coil, or the furnace heat exchanger), the duct system that is connected to the new or replaced space conditioning equipment, if the duct system meets the criteria of Section 144 (k) 1, 2., and 3, shall be sealed, as confirmed through field verification and diagnostic testing in accordance with procedures for duct sealing of existing duct systems as specified in the Nonresidential ACM Manual, to one of the requirements of Section 149 (b) 1 D; and

EXCEPTION 1 to Section 149 (b) 1. E: Buildings altered so that the duct system no longer meets the criteria of Section 144 (k) 1, 2, and 3.

Ducts would no longer have to be sealed if the roof deck was insulated and attic ventilation openings sealed.

EXCEPTION 2 to Section 149 (b) 1 E: Duct systems that are documented to have been previously sealed as confirmed through field verification and diagnostic testing in accordance with procedures in the Nonresidential ACM Manual.

EXCEPTION 3 to Section 149 (b) 1 E: Existing duct systems constructed, insulated or sealed with asbestos.

There are new requirements in 2005 when using the performance approach for compliance, analyzing the whole building and making improvements in the existing building. Changes to the existing building are alterations and must meet the requirements of §149(b)2.B.

§149 (b) 2 B requires that the energy efficiency of either the building or permitted space shall be improved so that the building or permitted space meets the energy budget in Section 141 that would apply to the building or permitted space, if the building envelope was unchanged, except for roof alterations subject to Section 149 (b) 1 B, the roof alteration met the requirements of 149 (b) 1; and for any mechanical system alterations subject to Section 149(b) 1 C, D, E, the mechanical system alterations met the requirements of Section 149 (b) 1, and for any lighting system alterations subject to Section 149 (b) 1 F, the lighting system alteration met the requirements of Section 149 (b) 1; and for any service water-heating system alteration subject to Section 149 (b) 1 K, the service water-heating system met the requirements of Section 149 (b) 1.

When existing heating, cooling, or service water heating systems or components are moved within a building, the existing systems or components need not comply with mandatory measures nor with the prescriptive or performance compliance requirements.

Performance approach may also be used to demonstrate compliance for alterations. Refer to Chapter 7, Performance Approach, for more details.

Acceptance tests must be conducted on the following equipment or systems when installed in new additions:

- Variable air volume systems.
- Constant volume systems.
- Package systems.
- Air distribution systems.
- Economizers.
- Demand control ventilation systems.
- Variable frequency drive fan systems.
- Hydronic control systems.
- Hydronic pump isolation controls and devices.
- Supply water reset controls.
- Water loop heat pump control.
- Variable frequency drive pump systems.
- System programming.
- Time clocks.

For more detail, see Chapter 8, Acceptance Requirements.

4.10 Glossary/Reference

Terms used in this chapter are defined in Joint Appendix I. Definitions that appear below either expand on the definition in Joint Appendix I or are terms that are not included in that appendix, but are included here as an aid in understanding the sections that follow.

4.10.1 Definitions of Efficiency

Sections 111 and 112 mandate minimum efficiency requirements that regulated appliances and other equipment must meet. The following describes the various measurements of efficiency used in the Standards.

The purpose of space-conditioning and water-heating equipment is to convert energy from one form to another, and to regulate the flow of that energy. Efficiency is a measure of how effectively the energy is converted or regulated. It is expressed as the ratio:

Equation 4-1

$$Efficiency = \frac{Output}{Input}$$

The units of measure in which the input and output energy are expressed may be either the same or different, and vary according to the type of equipment. The Standards use several different measures of efficiency.

Combustion Efficiency is defined in the Appliance Efficiency Standards as follows:

"Combustion efficiency of a space heater" means a measure of the percentage of heat from the combustion of gas or oil that is transferred to the space being heated or lost as jacket loss, as determined using the applicable test method in Section 1604(e).

and;

"Boiler" means a space heater that is a self-contained appliance for supplying steam or hot water primarily intended for space-heating. "Boiler" does not include hot water supply boilers.

Where boilers used for space heating are considered to be a form of space heater.

Thermal efficiency is used as the efficiency measurement for gas and oil boilers with rated input greater than or equal to 300,000 Btu/hr. It is a measure of the percent of energy transfer from the fuel to the heat exchanger (HX). Input and output energy are expressed in the same units so that the result has non-dimensional units:

Equation 4-2

$$\%\ \text{Combustion Eff} = \frac{(\text{Energy to HX}) \times 100}{\text{Total Fuel Energy Input}}$$

Note: combustion efficiency does not include losses from the boiler jacket. It is strictly a measure of the energy transferred from the products of combustion.

Fan Power Index is the hourly power consumption of the fan system per unit of air moved per minute (W/cfm).

Thermal Efficiency is defined in the Appliance Efficiency Regulations as a measure of the percentage of heat from the combustion of gas, which is transferred to the space or water being heated as measured under test conditions specified. The definitions from the Appliance Efficiency Regulations are:

"Thermal efficiency" of a space heater means a measure of the percentage of heat from the combustion of gas or oil that is transferred to the space being heated, or in the case of a boiler, to the hot water or steam, as determined using the applicable test methods in Section 1604(e).

"Thermal efficiency" of a water heater means a measure of the percentage of heat from the combustion of gas or oil that is transferred to the water, as determined using the applicable test method in Section 1604(f).

"Thermal efficiency" of a pool heater means a measure of the percentage of heat from the input that is transferred to the water, as determined using the applicable test method in Section 1604(g).

Equation 4-3

$$\%\ Thermal\ Eff = \frac{(Energy\ Transferred\ to\ Medium)}{(Total\ Fuel\ Input)}$$

4.10.2 Definitions of Spaces and Systems

The concepts of spaces, zones, and space-conditioning systems are discussed in this subsection.

Fan System is a fan or collection of fans that are used in the scope of the Prescriptive requirement for fan-power limitations [§144(c)]. Section 144(c) defines fan-systems as all fans in the system that are required to operate at design conditions in order to supply air from the heating or cooling source to the conditioned space, and to return it back to the source or to exhaust it to the outdoors. For cooling systems this includes supply fans, return fans, relief fans, fan coils, series-style fan powered boxes, parallel-style fan powered boxes and exhaust fans. For systems without cooling this includes supply fans, return fans, relief fans, fan coils, series-style fan powered boxes, parallel-style fan powered boxes and exhaust fans. Parallel-style fan-powered boxes are often not included in a terminal unit where there is no need for heating as the fans are only needed for heating.

Space is not formally defined in the Standards, but is considered to be an area that is physically separated from other areas by walls or other barriers. From a mechanical perspective, the barriers act to inhibit the free exchange of air with other spaces. The term "space" may be used interchangeably with "room."

Zone, Space Conditioning is a space or group of spaces within a building with sufficiently similar comfort conditioning requirements so that comfort conditions, as specified in Section 144(b)3 or Section 150(h), as applicable, can be maintained throughout the zone by a single controlling device. It is the designer's responsibility to determine the zoning; in most cases each building exposure will consist of at least one zone. Interior spaces that are not affected by outside weather conditions usually can be treated as a single zone.

A building will generally have more than one zone. For example, a facility having 10 spaces with similar conditioning that are heated and cooled by a single space-conditioning unit using one thermostat is one zone. However, if a second thermostat and control damper, or an additional mechanical system, is added to separately control the temperature within any of the 10 spaces, then the building has two zones.

The term **Space-Conditioning System** is used to define the scope of Standards requirements. It is a catch-all term for mechanical equipment and distribution systems that *provide either collectively or individually- heating, ventilating, or cooling within or associated with conditioned spaces in a building.* HVAC equipment is considered part of a space-conditioning system if it does not exclusively serve a process within the building. Space conditioning systems include general and toilet exhaust systems.

Space-conditioning systems may encompass a single HVAC unit and distribution system (such as a package HVAC unit) or include equipment that services multiple HVAC units (such as a central outdoor air supply system, chilled water plant equipment or central hot water system).

4.10.3 Types of Air

Exhaust Air is air being removed from any space or piece of equipment and conveyed directly to the atmosphere by means of openings or ducts. The exhaust may serve specific areas, such as toilet rooms, or may be for a general building relief, such as an economizer.

Make-up Air is air provided to replace air being exhausted.

Mixed Air is a combination of supply air from multiple air streams. The term *mixed air* is used in the Standards in an exception to the prescriptive requirement for space conditioning zone controls [§144(d)]. In this manual the term mixed air is also used to describe a combination of outdoor and return air in the mixing plenum of an air handling unit.

Outdoor Air *is air taken from outdoors and not previously circulated in the building.* For the purposes of ventilation, outdoor air is used to flush out pollutants produced by the building materials, occupants and processes. To ensure that all spaces are adequately ventilated with outdoor air, the Standards require that each space be adequately ventilated (see 4.3).

Return Air is air from the conditioned area that is returned to the conditioning equipment either for reconditioning or exhaust. The air may return to the system through a series of ducts, or through plenums and airshafts.

Supply Air is air being conveyed to a conditioned area through ducts or plenums from a space-conditioning system. Depending on space requirements, the supply may be heated, cooled, or neutral.

Transfer Air is air that is transferred directly from either one space to another or from a return plenum to a space. Transfer air is a way of meeting the ventilation requirements at the space level and is an acceptable method of ventilation per §121. It works by transferring air with a low level of pollutants (from an over ventilated space) to a space with a higher level of pollutants (see Section 4.3).

4.10.4 Air Delivery Systems

Space-conditioning systems can be grouped according to how the airflow is regulated.

Constant Volume System is a space-conditioning system that delivers a fixed amount of air to each space*.* The volume of air is set during the system commissioning.

Variable Air Volume (VAV) System *is a space conditioning system that maintains comfort levels by varying the volume of conditioned air to the zones served.* This system delivers conditioned air to one or more zones. There are two styles of VAV systems, single-duct VAV where mechanically cooled air is typically supplied and reheated through a duct mounted coil, and dual-duct VAV systems where heated and cooled streams of air are blended at the zone level. In single-duct VAV systems the duct serving each zone is provided with a motorized damper that is modulated by a signal from the zone thermostat. The thermostat also controls the reheat coil. In dual-duct VAV systems the ducts serving each zone are provided with motorized dampers that blend the supply air based on a signal from the zone thermostat.

Pressure Dependent VAV Box has an air damper whose position is controlled directly by the zone thermostat. The actual airflow at any given damper position is a function of the air static pressure within the duct. Because airflow is not measured, this type of box cannot precisely control the airflow at any given moment: a pressure dependent box will vary in output as other boxes on the system modulate to control their zones.

Pressure Independent VAV Box has an air damper whose position is controlled on the basis of measured airflow. The setpoint of the airflow controller is, in turn, reset by a zone thermostat. A maximum and minimum airflow is set in the controller, and the box modulates between the two according to room temperature.

4.10.5 Return Plenums

Return Air Plenum is an plenum is an air compartment or chamber including uninhabited crawl spaces, areas above a ceiling or below a floor, including air spaces below raised floors of computer/data processing centers, or attic spaces, to which one or more ducts are connected and which forms part of either the supply air, return air or exhaust air system, other than the occupied space being conditioned. The return air temperature is usually within a few degrees of space temperature.

4.10.6 Zone Reheat, Recool and Air Mixing

When a space-conditioning system supplies air to one or more zones, different zones may be at different temperatures because of varying loads. Temperature regulation is normally accomplished by varying the conditioned air supply (variable volume), by varying the temperature of the air delivered, or by a combination of supply and temperature control. With multiple zone systems, the ventilation requirements or damper control limitations may cause the cold air supply to be higher than the zone load, this air is tempered through reheat or mixing with warmer supply air to satisfy the actual zone load. §144(c) limits the amount of energy used to simultaneously heat and cool the same zone as a basis of zone temperature control

[**Zone**] **Reheat** *is the heating of air that has been previously cooled by cooling equipment or systems or an economizer.* A heating device, usually a hot water coil, is placed in the zone supply duct and is controlled via a zone thermostat. Electric reheat is sometimes used, but is severely restricted by the Standards.

[**Zone**] **Recool** *is the cooling of air that has been previously heated by space conditioning equipment or systems serving the same building.* A chilled water or refrigerant coil is usually placed in the zone supply duct and is controlled via a zone thermostat. Re-cooling is less common than reheating.

Zone Air Mixing occurs when more than one stream of conditioned air is combined to serve a zone. This can occur at the HVAC system (e.g. multizone), in the ductwork (e.g. dual-duct system) or at the zone level (such as a zone served by a central cooling system and baseboard heating). In some multizone and dual duct systems an unconditioned supply is used to temper either the heating or cooling air through mixing. §144(c) only applies to systems that mix heated and cooled air.

4.10.7 Economizers

Air Economizer is a ducting arrangement and automatic control system that allows a cooling supply fan system to supply outside air to reduce or eliminate the need for mechanical cooling.

When the compliance path chosen for meeting the Standards requires an economizer, the economizer must be integrated into the system so that it is capable of satisfying part of the cooling load while the rest of the load is satisfied by the refrigeration equipment. The Standards also require that all new economizers meet the Acceptance Requirements for Code Compliance before a final occupancy permit may be granted. The operation of an integrated air economizer is diagrammed in Figure 4-22. When outdoor air is sufficiently cold, the economizer satisfies all cooling demands on its own. As the outdoor temperature (or enthalpy) rises, or as system cooling load increases, a point may be reached where the economizer is no longer able to satisfy the entire cooling load. At this point the economizer is supplemented by mechanical refrigeration, and both operate concurrently. Once the outside drybulb temperature (for temperature controlled economizer) or enthalpy (for enthalpy economizers) exceeds that of the return air or a predetermined high limit, the outside air intake is reduced to the minimum required, and cooling is satisfied by mechanical refrigeration only.

Nonintegrated economizers cannot be used to meet the economizer requirements of the prescriptive compliance approach. In nonintegrated economizer systems, the economizer may be interlocked with the refrigeration system to prevent both from operating simultaneously. The operation of a nonintegrated air economizer is diagrammed in Figure 4-23. Nonintegrated economizers can only be used if they comply through the performance approach.

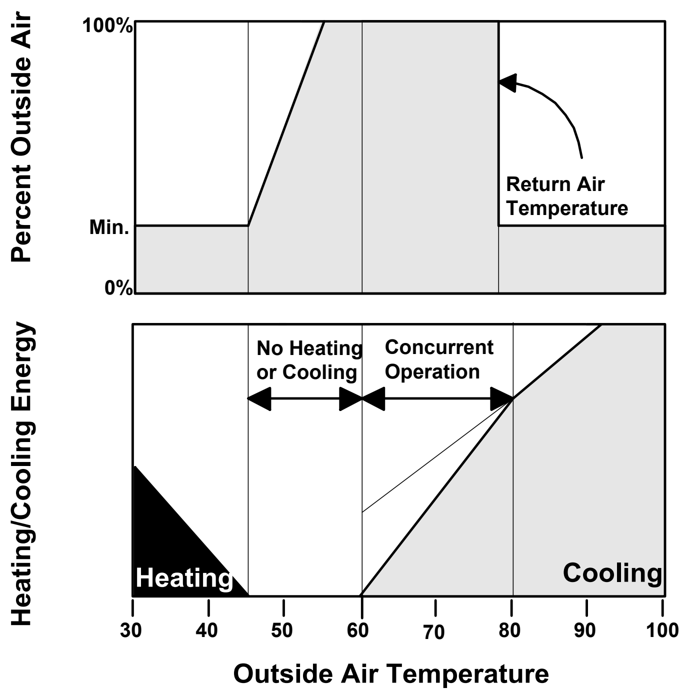


Figure 4-22 – Integrated Air Economizer

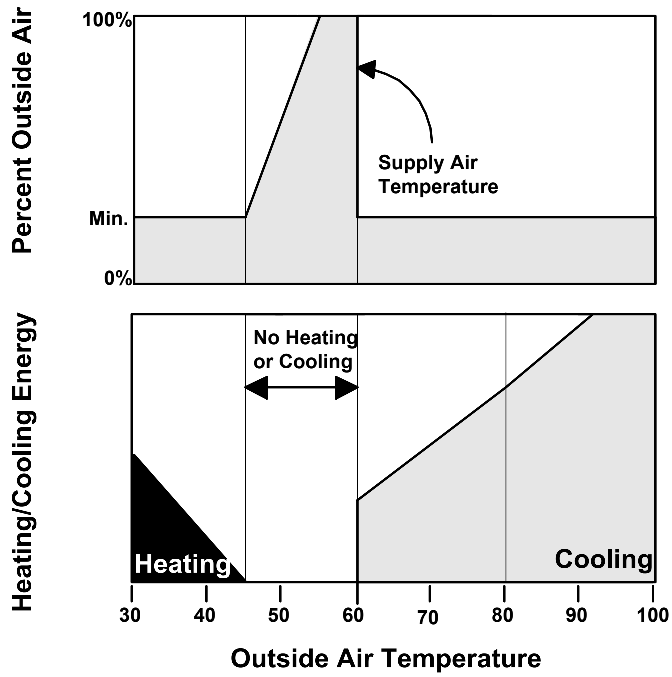


Figure 4-23 – Nonintegrated Air Economizer

Water Economizer is a system by which the supply air of a cooling system is cooled directly or indirectly by evaporation of water, or other appropriate fluid, in order to reduce or eliminate the need for mechanical cooling.

As with an air economizer, a water economizer must be integrated into the system so that the economizer can supply a portion of the cooling concurrently with the refrigeration system.

There are three common types of water-side economizers:

1. **"Strainer-cycle" or chiller-bypass water economizer**. This system, depicted in Figure 4-24 below, does *not* meet the prescriptive requirement as it cannot operate in parallel with the chiller. This system is applied to equipment with chilled water coils.

2. **Water-precooling economizer**. This system depicted in Figure 4-25 and Figure 4-26 below *does* meet the prescriptive requirement if properly sized. This system is applied to equipment with chilled water coils.

3. **Air-precooling water economizer**. This system depicted in Figure 4-27 below *also meets* the prescriptive requirement if properly sized. The air-precooling water economizer is appropriate for water-source heat pumps and other water-cooled HVAC units.

To comply with the prescriptive requirements, the cooling tower serving a water-side economizer must be sized for 100% of the anticipated cooling load at the off-design outdoor-air condition of 50°Fdb/45°Fwb. This requires rerunning the cooling loads at this revised design condition and checking the selected tower to ensure that it has adequate capacity.

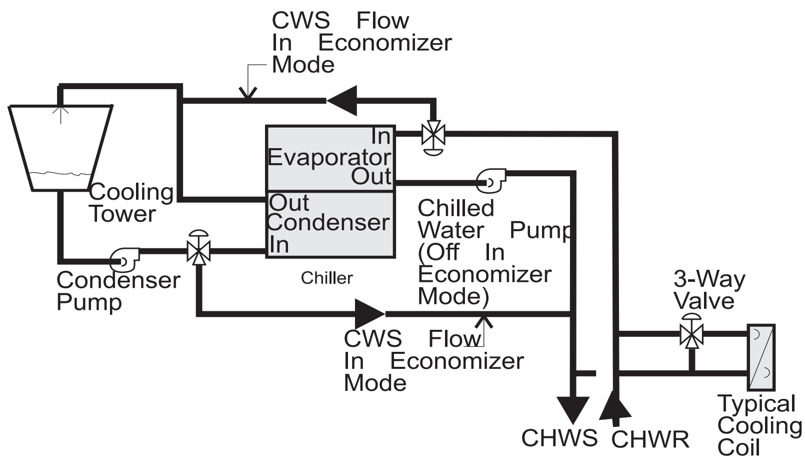


Figure 4-24 – "Strainer-Cycle" Water Economizer
This system does not meet the prescriptive requirement as it cannot operate in parallel with the chiller

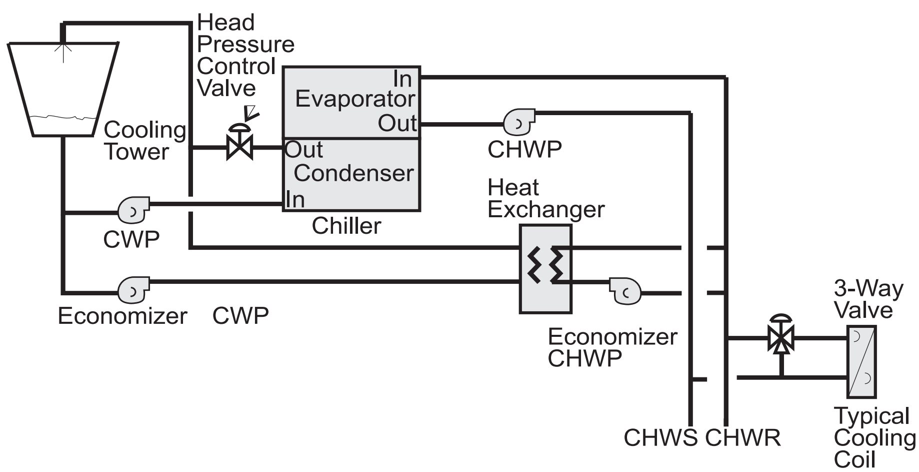


Figure 4-25 – Water-Precooling Water Economizer with Three-Way Valves

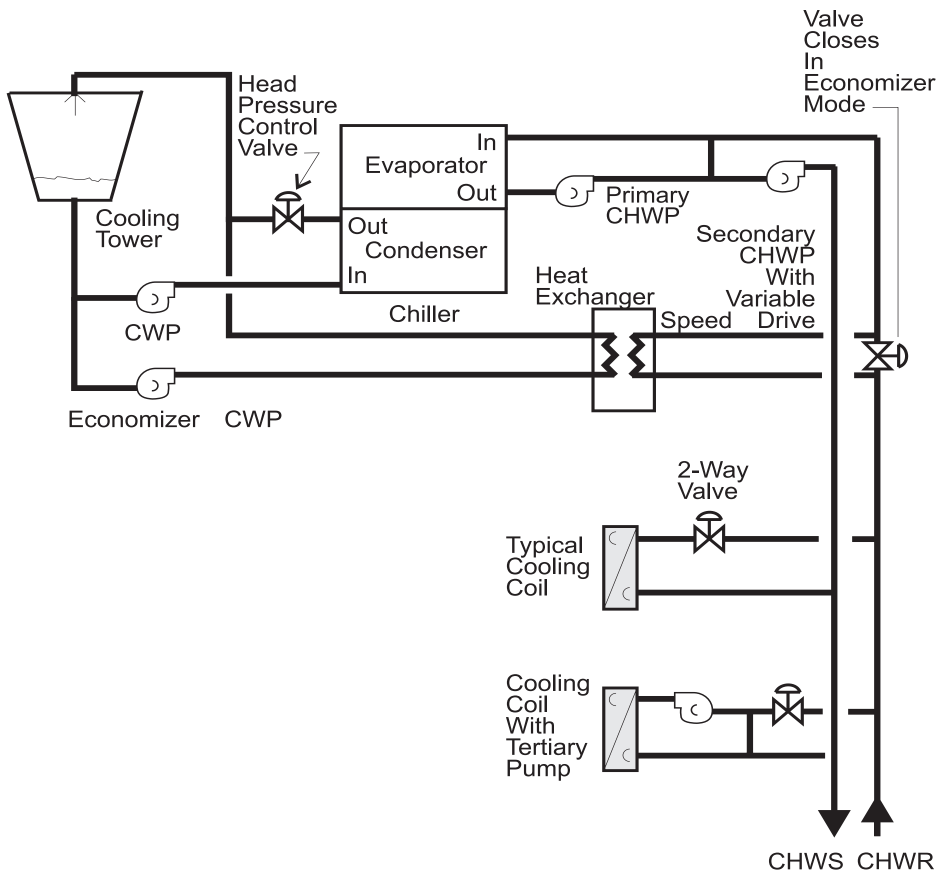


Figure 4-26 – Water-Precooling Water Economizer with Two-Way Valves

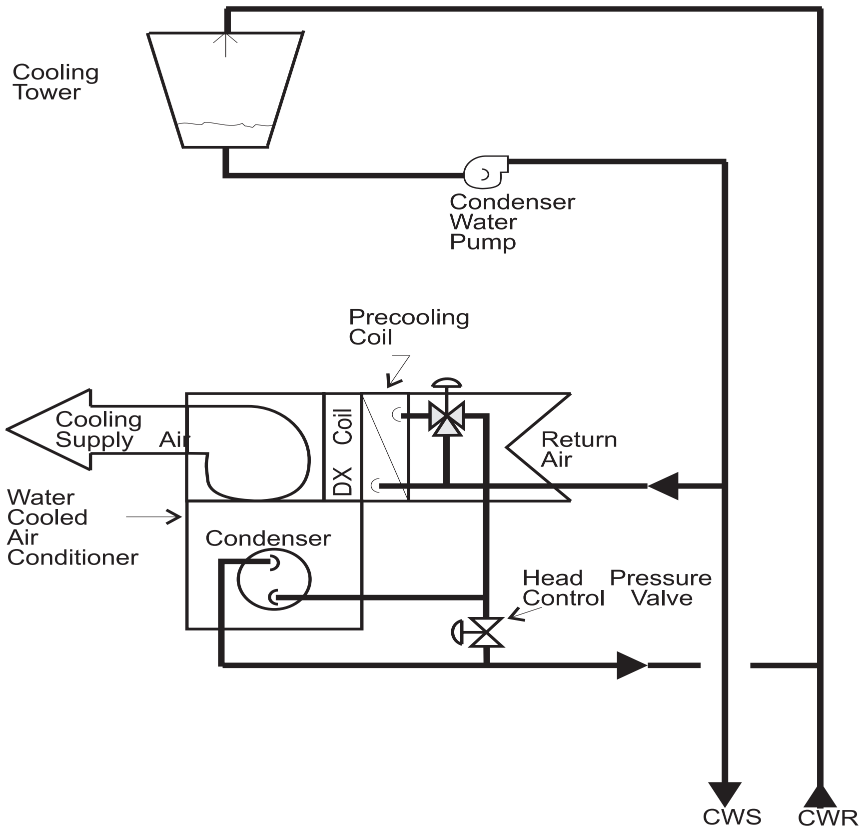


Figure 4-27 – Air-Precooling Water Economizer

4.10.8 Unusual Sources of Contaminants

Section 121 addresses ventilation requirements for buildings and uses the term of “unusual sources of contamination.” In this context, such contaminants are considered to be chemicals, materials, processes or equipment that produce pollutants which are considered harmful to humans, and are not typically found in most building spaces. Examples may include some cleaning products, blueprint machines, heavy concentrations of cigarette smoke and chemicals used in various processes.

The designation of such spaces is left to the designer’s discretion, and may include considerations of toxicity, concentration and duration of exposure. For example, while photocopiers and laser printers are known to emit ozone, scattered throughout a large space it may not be of concern. A heavy concentration of such machines in a small space may merit special treatment (See Section 4.3).

4.10.9 Demand Controlled Ventilation

Demand controlled ventilation is required for use on systems that have an outdoor air economizer, and serve a space with a design occupant density, or maximum occupant load factor for egress purposes in the CBC, greater than or equal to 25 people per 1000 ft^2 (40 square foot per person) [§121(c)3]. Demand controlled ventilation is also allowed as an exception in the ventilation requirements for intermittently occupied systems [§121(c)1, §121(c)3 and §121(c)4]. It is a concept in which the amount of outdoor air used to purge one or more offending pollutants from a building is a function of the measured level of the pollutant(s).

§121 allows for demand controlled ventilation devices that employ a carbon dioxide (CO_2) sensor. Carbon dioxide sensors measure the level of carbon dioxide, which is used as a proxy for the amount of pollutant dilution in densely occupied spaces. CO_2 sensors have been on the market for many years and are available with integrated self-calibration devices that maintain a maximum guaranteed signal drift over a 5-year period. ASHRAE Standard 62 provides some guidelines on the application of demand controlled ventilation.

Demand controlled ventilation is available at either the system level (used to reset the minimum position on the outside air damper) and at the zone level (used to reset the minimum airflow to the zone). The zone level devices are sometimes integrated into the zone thermostat.

4.10.10 Intermittently Occupied Spaces

The demand controlled ventilation devices discussed here are allowed and/or required only in spaces that are intermittently occupied. An intermittently occupied space is considered to be an area that is infrequently or irregularly occupied by people. Examples include auction rooms, movie theaters, auditoriums, gaming rooms, bars, restaurants, conference rooms and other assembly areas. Because the standard requires base ventilation requirement in office spaces that are very close to the actual required ventilation rate at 15 cfm per person, these controls may not save significant amounts of energy for these low-density applications. However, even in office applications, some building owners may install CO_2 sensors as a way to monitor ventilation conditions and alert to possible malfunctions in building air delivery systems.

4.11 Mechanical Plan Check Documents

At the time a building permit application is submitted to the building department, the applicant also submits plans and energy compliance documentation. This section describes the forms and recommended procedures documenting compliance with the mechanical requirements of the Standards. It does not describe the details of the requirements; these are presented in Section 4.2. The following discussion is addressed to the designer preparing construction documents and compliance documentation, and to the building department plan checkers who are examining those documents for compliance with the Standards.

The use of each form is briefly described below and then complete instructions for each form are presented in the following subsections. The information and format of these forms may be included in the equipment schedule.

MECH-1-C: Certificate of Compliance
This form is required for every job, and it is required to appear *on the plans*.

MECH-2-C: Air, Water Side, and Service Hot Water & Pool System Requirements
This form summarizes the major components of the heating and cooling systems, and service hot water & pool systems, and documents the location on the plans and in the specifications where the details about the requirements appear.

MECH-3-C: Mechanical Ventilation and Reheat
This form documents the calculations used as the basis for the outdoor air ventilation rates. For VAV systems, it is also used to show compliance with the reduced airflow rates necessary before reheating, re-cooling or mixing of conditioned airstreams.

MECH-4-C: HVAC Misc. Prescriptive Requirements: Other
This form is used to list fan power consumption limits, electric resistance heating system capacity, and centrifugal fan cooling tower limits, and air-cooled chiller limits requirements.

4.11.1 MECH-1-C: Certificate of Compliance

MECH-1-C is the primary mechanical form. Its purpose is to provide compliance information in a form useful to the enforcement agency's field inspectors.

This form should be included on the plans, usually near the front of the mechanical drawings. A copy of these forms should also be submitted to the building department along with the rest of the compliance submittal at the time of building permit application. With building department approval, the applicant may use alternative formats of these forms (rather than the Energy Commission's forms), provided the information is the same and in similar format.

Project Description

- PROJECT NAME is the title of the project, as shown on the plans and known to the building department.
- DATE is the date of preparation of the compliance submittal package. It should be on or after the date of the plans, and on or before the date of the building permit application.
- PROJECT ADDRESS is the address of the project as shown on the plans and known to the building department.
- PRINCIPAL DESIGNER - MECHANICAL is the person responsible for the preparation of the mechanical plans, and the person who signs the STATEMENT OF COMPLIANCE (see below). The person's telephone number is given to facilitate response to any questions that arise.

- TELEPHONE is the contact phone number of the principal designer or the mechanical engineer in charge of the project.
- DOCUMENTATION AUTHOR is the person who prepared the energy compliance documentation. This may or may not be the principal designer (it may be a person specializing in Standards compliance work). The person's telephone number is given to facilitate response to any questions that arise.
- TELEPHONE is the contact phone number of the documentation author for the project.
- ENFORCEMENT AGENCY USE is reserved for building department record keeping purposes.

General Information

1. DATE OF PLANS is the last revision date of the plans. If the plans are revised after this date, it may be necessary to re-submit the compliance documentation to reflect the altered design. The building department will determine whether or not the revisions require this.

2. BUILDING CONDITIONED FLOOR AREA has specific meaning under the Standards.

The number entered here should match the floor area entered on form ENV-CC-1-05.

3. CLIMATE ZONE is the California Climate zone in which this project is located. See Joint Appendix II for a listing of climate zones.

4. BUILDING TYPE is specified because there are special requirements for high-rise residential and hotel/motel guest room occupancies. All other occupancies that fall under the Nonresidential Standards are designated "Nonresidential" here. It is possible for a building to include more than one building type.

5. PHASE OF CONSTRUCTION indicates the status of the building project described in the documents. Refer to Section **1.6** for detailed discussion of the various choices.

a. NEW CONSTRUCTION should be checked for all new buildings, newly conditioned space or for new construction in existing buildings (tenant improvements, see Section **1.7.10**) that are submitted for envelope compliance.

b. ADDITION should be checked for an addition which is not treated as a stand-alone building, but which uses Option 2 described in Section **1.7.12**. Tenant improvements that increase conditioned floor area and volume are additions.

c. ALTERATION should be checked for alterations to existing building mechanical systems (see Section **1.7.11**). Tenant improvements are usually alterations.

d. UNCONDITONED SPACE - An affidavit is required that no mechanical system are being installed in a newly constructed enclosed unconditioned buildings. If lighting is installed it must meet all the lighting requirements (see Section **1.7.8**).

6. PROOF OF ENVELOPE COMPLIANCE indicates how the envelope has been shown to comply. The envelope must comply before a permit to install a mechanical system is granted:

- PREVIOUS ENVELOPE PERMIT indicates that the envelope has already been shown to comply. If so, the building department will have the envelope forms on file. This method is typically used for alterations to existing space.
- ENVELOPE COMPLIANCE ATTACHED is typically used for new buildings.

Statement of Compliance

The Statement of Compliance is signed by both the Documentation Author and the Principal Mechanical Designer who is responsible for preparation of the plans for the building. This latter person is also responsible for the energy compliance documentation, even if the actual work is delegated to a different person acting as Documentation Author. It is necessary that the compliance documentation be consistent with the plans.

The Business and Professions Code governs who is qualified to prepare plans, and therefore to sign this statement; check the appropriate box that describes the signer's eligibility. See Section **2.3.3** in this manual for more information on the Business and Professions Code.

Acceptance Requirements
The Designer is required to check the box for each type of lighting system in the building when an acceptance test is required. Below each box that is checked the Designer is required to list the equipment that must be tested and the number of systems to be tested in parentheses. The Designer should think abut who will be conducting the tests and list this person in the section titled "Test Performed By". Those who are allowed to conduct the tests are the installing contractor, design professional or an agent selected by the owner.

4.11.2 MECH-2-C Overview

Mechanical Mandatory and Prescriptive Measures

The mandatory measures and prescriptive measures must be incorporated into the construction documents. MECH-2-C (Parts 1, 2, and 3) list the measures and the section numbers in the Building Efficiency Standards where the requirements for those measures are specified. The columns labeled *Reference on Plans or Specifications* are for designating the specific sheet on the plans or specification section(s) where the measures used to comply with the standards are documented. As noted below the table, a reference to specifications must include both a specification section and paragraph number. The remaining cells in this form are organized with a separate column for each system (or groups of similar systems). In each column, the documentation author shall identify where each of the required measures are specified on the plans or in the project specifications. Where a measure is not applicable to the specific system, the letters “NA” (for not applicable) are placed in the cell. Groups of similar systems can be entered in a single column where appropriate.

In the plans or specifications where the specific details of compliance are shown, the designer may use whatever format is most appropriate for specifying the required measures. This will generally take one of several forms:

- The material is incorporated into an equipment schedule on the mechanical plans. This includes items like equipment efficiencies, capacities (desired equipment size and calculated required capacity) and some features like air-side economizers.
- The material appears on the plans in a general notes block. An example of these are the “mandatory measures block” that was used in previous versions of the Standards.
- The material is incorporated into the specifications. For most control measures this will be in the sequences of operations under the controls specification section. For equipment features like tower flow turndown or heat pump thermostats this will typically be in either the equipment schedules or the specification sections for the specific piece of equipment. Where specifications are used, the documentation must be specific enough to point the code official to the page (or specific paragraph) where the feature is specified.

The information on this form may be incorporated into the plans or on a spreadsheet.

4.11.3 MECH-2-C (Part 1 of 3) Air System Requirements

Item or System Tags

At the start of each column identify each air-side unit or groups of similar units using the system tag(s) from the plans or specifications.

MANDATORY MEASURES

For each item below, identify the plan or specification section where the required feature is specified.

- HEATING EQUIPMENT EFFICIENCY – This is the minimum code-mandated heating equipment efficiency. Where appropriate both full- and part-load efficiency must be identified.
- COOLING EQUIPMENT EFFICIENCY – This is the minimum code-mandated cooling equipment efficiency. Note both the full- and part-load efficiencies must be identified.
- HEAT PUMP THERMOSTAT – For heat pump systems indicate the controls which minimize the use of electric resistance heat as required by §112 (b). The electric resistance heat can only be used for defrost and as a second stage of heating.
- FURNACE CONTROLS – The specified plan sheet must indicate the furnace control requirements of §112 (c) (IID and power venting or

flue damper for furnaces ≥225MBH input rating) and §115 (a) (ignition by other than a pilot light).

- NATURAL VENTILATION – The specifications for operable openings, their control (if appropriate) and location. Note this will likely cross reference architectural plans.
- MINIMUM VENTILATION – The specification for minimum OSA at both the central and zone levels in compliance with §112 (b).
- VAV MINIMUM POSITION CONTROL – For VAV systems identify the specifications for control of minimum OSA at the central system as the airflow turns down.
- DEMAND CONTROL VENTILATION – If demand control ventilation systems are either required or provided [§121 (c)] identify the specifications for the CO_2 sensors and controls.
- TIME CONTROL - Identify the control specifications for preoccupancy purge [§121 (c)] and scheduling control [§122 (e)] for each system. This item should be in the control sequences or in the specification for a timeclock or programmable thermostat.
- SETBACK AND SETUP CONTROL - If setback or setup controls are required identify the specifications for these off hour controls. This item should be in the control sequences.
- OUTDOOR DAMPER CONTROL – Identify the specifications for automatic or barometric dampers on OSA and exhaust openings.
- ISOLATION ZONES – Identify the specifications for isolation zone controls that are required by §122 (g) for units serving multiple floors or areas in excess of 25,000 ft^2. This item should be in the control sequences.
- PIPE INSULATION – Identify the specifications for pipe insulation greater than or equal to the requirements of §123. Note this is only for the refrigerant piping on split-systems. Hydronic insulation is identified on form MECH-2-C (Part 2 of 3).
- DUCT INSULATION – Identify the specifications for duct insulation greater than or equal to the requirements of §124.

PRESCRIPTIVE MEASURES

- CALCULATED HEATING CAPACITY – For units with electric resistance, heat pump or furnace heating either enter the calculated heating capacity in the form or put it on the plans or in the specifications and identify the location in this field. This information could be added to the equipment schedules. For units with hydronic or steam heating enter “NA.”
- PROPOSED HEATING CAPACITY – For units with electric resistance, heat pump or furnace heating, identify the specification for the proposed unit heating capacity. This is typically the equipment schedule. For units with hydronic or steam heating enter “NA.”

- CALCULATED COOLING CAPACITY – For units with DX cooling either enter the calculated cooling capacity in the form or put it on the plans or in the specifications and identify the location in this field. This information could be added to the equipment schedules. For units with hydronic cooling enter "NA."
- PROPOSED COOLING CAPACITY – For units with DX cooling, identify the specification for the proposed unit cooling capacity. This is typically the equipment schedule. For units with hydronic cooling enter "NA."
- FAN CONTROL – For VAV systems, identify the specifications for fan volume control per §144 (c). For constant volume systems, enter NA in these cells. For VAV fan systems over 10 hp, the modulation must be one of the following:

  Variable pitch vanes.

  Variable frequency drive or variable-speed drive.

  Other. A specification for a device that has a 70% power reduction at 50% airflow with a design pressure setpoint of 1/3 of the fan total static pressure.
- DP SENSOR LOCATION – Indicate the specification for the placement of the fan pressure sensor to meet the requirements of §144 (c) 2 C. For constant volume systems and VAV systems with DDC controls to the zone level enter "NA."
- SUPPLY PRESSURE RESET (DDC only) – For systems with DDC controls to the zone level indicate the sequence of operation that provides supply pressure reset by zone demand.
- SIMULTANEOUS HEAT/COOL – Indicate the controls or sequences that stage the heating and cooling or for VAV systems reduces the supply before turning on the zone heating.
- ECONOMIZER – Indicate the specification for an air or water economizer that meets the requirements of §144 (e). The specification must include details of the high limit switch for airside economizers. If an economizer is not required indicate by entering "NA."
- HEAT AND COOL SUPPLY RESET – Indicate the specification for supply temperature reset controls per §144 (f). This will typically be a sequence of operation. This control is required for systems that reheat, re-cool, or mix conditioned air streams.
- DUCT SEALING – Indicate the specification for duct leakage testing where required by §144 (k). Note this only applies to small single units with either horizontal discharge or ducts in uninsulated spaces.

4.11.4 MECH-2-C (Part 2 of 3) Water Side System Requirements

Item or System Tags

At the start of each column identify each chiller, tower, boiler, and hydronic loop (or groups of similar units) using the system tag(s) from the plans or specifications.

MANDATORY MEASURES

- This is the minimum code-mandated heating or cooling equipment efficiency. Where appropriate both full- and part-load efficiency must be identified. This is typically identified in the equipment schedules.
- PIPE INSULATION – Identify the specifications for pipe insulation greater than or equal to the requirements of §123.

PRESCRIPTIVE MEASURES

- CALCULATED CAPACITY – For central chillers or boilers enter the calculated capacity in the form or put it on the plans or in the specifications and identify the location in this field. This information could be added to the equipment schedules.
- PROPOSED HEATING CAPACITY – For central chillers or boilers identify the specification for the proposed unit capacity. This is typically the equipment schedule.
- TOWER FAN CONTROLS – For cooling towers identify the specifications for fan volume control per §144 (h). Each fan motor 7.5 hp and larger must have a variable speed drive, pony motor or two-speed motor for no less than 2/3rds of the tower cells.
- TOWER FLOW CONTROLS – For cooling towers identify the specifications for tower flow control per §144 (h). Each tower cell must turn down to 33% or the capacity of the smallest pump which ever is larger.
- VARIABLE FLOW SYSTEM DESIGN – Identify the specifications for two way valves on chilled and hot water systems with more than 3 control valves. This is often shown on the chilled or hot water piping schematic or riser diagram. It is also sometimes identified in the coil schedules.
- CHILLER AND BOILER ISOLATION – Identify the specifications for actuated isolation of chiller and boilers in a plant with multiple pieces of equipment and headered pumps. Note this requirement is inherently met by chillers and boilers with dedicated pumps. This is often shown on the chilled or hot water piping schematic.
- CHW AND HHW RESET CONTROLS – Indicate the specification for supply water temperature reset controls per §144(j) 4. This will typically be a sequence of operation.
- WLHP ISOLATION VALVES – Indicate the specification for water loop heat pump isolation valves to meet the requirements of §144(j) 5.

- VSD ON CHW & CW PUMPS > 5HP – Indicate the specification for variable speed drives on variable flow systems with greater than five horsepower as indicated in §144(j) 6.
- DP LOCATION – Indicate the specification for the placement of the pump pressure sensor to meet the requirements of §144(j) 6.

4.11.5 MECH-2-C (Part 3 of 3) Service Hot Water & Pool Requirements

Item or System Tags

- At the start of each column identify each service hot water, pool heating, and spa heating system (or groups of similar units) using the system tag(s) from the plans or specifications.

MANDATORY MEASURES

- WATER HEATER CERTIFICATION – Indicate the specifications for automatic temperature controls capable of adjustment from the lowest to the highest acceptable temperature settings for the intended use as listed in Table 2, Chapter 49 of the ASHRAE Handbook, HVAC Applications Volume. Residential occupancies are exempt from this requirement.
- WATER HEATER EFFICIENCY – This is the minimum code-mandated water heating equipment efficiency and standby losses. Where appropriate both full- and part-load efficiency must be identified. This is typically identified in the equipment schedules.
- SERVICE WATER HEATING INSTALLATION – Indicate the specifications for the outlet temperature control, circulating service water-heating system control, public lavatory temperature control, and tank insulation requirements of §113(c)1 thorough §113(c)4. For newly constructed state buildings, the specified plans shall also show how the building meets the requirement to provide 60% of the energy needed for service water heating from site solar or recovered energy described in §113(c)5 or show that the state architect has determined that these systems are not economically or physically infeasible.
- POOL AND SPA EFFICIENCY AND CONTROL – Indicate the specifications for:
    - A minimum efficiency that complies with the Appliance Efficiency Regulations,
    - A readily accessible on-off switch, mounted on the outside of the heater that allows shutting off the heater without adjusting the thermostat setting;
    - A permanent, easily readable, and weatherproof plate or card that gives instruction for the energy efficient operation of the pool or spa and for the proper care of pool or spa water when a cover is used; and

    - A heating source that is not electric resistance.
    - Listed package units with fully insulated enclosures and tight-fitting covers insulated to at least R-6 may use electric resistance heating.
    - Pools or spas deriving at least 60% of the annual heating energy from site solar energy or recovered energy may use electric resistance heating.
- POOL AND SPA INSTALLATION – Indicate the specifications for:
    - At least 36 inches of pipe between the filter and the heater to allow for the future addition of solar heating equipment,
    - A cover for outdoor pools or outdoor spas,
    - Directional inlets and off-peak demand time switches for pools.
    - Pools or spas deriving at least 60% of the annual heating energy from site solar energy or recovered energy are accepted from the requirement for covers. Where public health standards require on-peak operations, directional inlets and time switches are not required.
- POOL HEATER – NO PILOT LIGHT – Indicate the specifications for ignition by other than a continuous burning pilot lights as required by §115(c).
- SPA HEATER – NO PILOT LIGHT – Indicate the specifications for ignition by other than a continuous burning pilot lights as required by §115(d).

4.11.6 MECH-3-C: Mechanical Ventilation and Reheat

This form is used to document the design outdoor ventilation rate for each space, and the total amount of outdoor air that will be provided by the space-conditioning or ventilating system. For VAV systems, this form also documents the reduced cfm to which each VAV box must control before allowing reheat.

One copy of this form should be provided for each mechanical system. Additional copies may be required for systems with a large number of spaces or zones. In lieu of this form, the required outdoor ventilation rates and airflows may be shown on the plans or the calculations can be presented in a spreadsheet.

Note that, in all of the calculations that compare a supply quantity to the REQ'D O.A. quantity, the actual percentage of outdoor air in the supply is ignored.

Areas in buildings for which natural ventilation is used should be clearly designated. Specifications must require that building operating instructions include explanations of the natural ventilation system.

Ventilation Calculations

- COLUMN A - ZONE/SYSTEM is the system or zone identifier as shown on the plans.
- AREA BASIS - Outdoor air calculations are documented in COLUMNS B, C and D. If a space is naturally ventilated, it should be noted here and the rest of the calculations (COLUMNS B-I and N) skipped.
    - COLUMN B - CONDITION AREA (SF) is the area in ft^2 for the SPACE, ZONE, or SYSTEM identified in COLUMN A.
    - COLUMN C - CFM PER SF is the minimum allowed outdoor ventilation rate as specified in Standards Table 121-A for the type of use listed.
    - COLUMN D - MIN CFM BY AREA is the minimum ventilation rate calculated by multiplying the CONDITION AREA in COLUMN B by the CFM PER Square Feet in COLUMN C.
- OCCUPANCY BASIS outdoor air calculations are calculated in COLUMNS E, F and G.
- COLUMN E - NUMBER OF PEOPLE is determined using one of the methods described in Section 4.3.2.
- COLUMN F - CFM PER PERSON is determined using one of the methods described in Section 4.3.2. Note this is generally 15 cfm/person.
- COLUMN G - MIN CFM BY OCCUPANT is the NUMBER OF PEOPLE multiplied by CFM PER PERSON.
- COLUMN H - REQ'D V.A is the larger of the outdoor ventilation rates calculated on an AREA BASIS or OCCUPANCY BASIS (COLUMN D or G).
- COLUMN I - DESIGN OUTDOOR AIR CFM is the actual outdoor air quantity to be provided based on cooling loads. If this quantity is less than the REQ'D V.A, then TRANSFER AIR (COLUMN N) will have to make up the difference.
- VAV MINIMUM. CFM calculations are made for variable air volume systems only, in COLUMNS J through M.
- COLUMN L, VAV MINIMUM CFM is the largest airflow to which the VAV box supply must be reduced before reheat is permitted. It is calculated as the largest of:
- COLUMN J - Enter 30% of the design zone airflow for cooling; or
- COLUMN K - CONDITION AREA (ft^2) (COLUMN B) x 0.4 cfm/ft^2; or 300 CFM

- COLUMN M – DESIGN MINIMUM SETPOINT. This design setpoint must be less than or equal to COLUMN L and greater than or equal to COLUMN H.
- COLUMN N - TRANSFER AIR is the amount of air that must be directly transferred from another space so that the space supply is always no less than REQ'D V.A

On a multiple zone system it is required if the value in COLUMN M is less than the value in COLUMN H. If required, it must be larger than

- TRANSFER AIR (COLUMN N) ≥ COLUMN H - COLUMN M

On a single zone system it is required if the value in COLUMN H is less than the OSA schedule for the unit. If required, it must be larger than

- TRANSFER AIR (COLUMN N) ≥ COLUMN H – Schedule OSA

TOTALS are summed for

- NUMBER OF PEOPLE – This should be consistent with the values used for the load calculations
- REQ'D V.A - The values listed on the plans as identified on MECH-2-C, Part 1 of 3 for Minimum Ventilation must be at least this amount. The designer may elect to use a greater amount of outdoor air judged necessary to ensure indoor air quality.
- DESIGN Ventilation AIR – This should be consistent with the values used for the load calculations

4.11.7 MECH-4-C: HVAC Misc. Prescriptive Requirements:

Fan Power Consumption

This form is used to document the calculations used in sizing equipment and demonstrating compliance with the fan power requirements when using the prescriptive approach. The PROJECT NAME and DATE, should be entered at the top of the form. See §144(c).

NOTE: Provide one copy of this worksheet for each fan system with a total fan system horsepower greater than 25 hp for Constant Volume Fan Systems or Variable Air Volume (VAV) Systems when using the Prescriptive Approach.

Fan Power Consumption

This section is used to show how the fans associated with the space-conditioning system comply with the maximum fan power requirements. All supply, return, exhaust fans, and space exhaust fans – such as toilet exhausts – in the space-conditioning system that operate during the peak design period must be listed. Included are supply/return/exhaust fans in packaged equipment. Economizer relief fans that do not operate at peak are excluded. Also excluded are all fans that are manually switched and all fans that are not directly associated with moving conditioned air to/from the space-conditioning system, such as condenser fans and cooling tower fans.

If the total horsepower of all fans in the system is less than 25 HP, then this should be noted in the FAN DESCRIPTION column and the rest of this section left blank. If the total system horsepower is not obvious, such as when a VAV system has many fan-powered boxes, then this section must be completed.

VAV fans and constant volume fans should be summarized on separate forms.

- COLUMN A - FAN DESCRIPTION lists the equipment tag or other name associated with each fan.
- COLUMN B - DESIGN BRAKE HORSEPOWER lists the brake horsepower, excluding drive losses, as determined from manufacturer's data.

For dual-fan, dual-duct systems, the heating fan horsepower may be the (reduced) horsepower at the time of the cooling peak. If unknown, it may be assumed to be 35% of design. If this fan will be shut down during the cooling peak, enter 0 in
COLUMN B.

If the system has fan-powered VAV boxes, the VAV box power must be included if these fans run during the cooling peak (i.e. series style boxes). The power of all boxes may be summed and listed on a single line. If the manufacturer lists power consumption in watts, then the wattage sum may be entered directly in COLUMN F. Horsepower must still be entered in COLUMN B if the designer intends to show that total system has less than 25 HP.

- COLUMNS C & D - EFFICIENCY lists the efficiency of the MOTOR and DRIVE. The default for a direct drive is 1.0; belt drive is 0.97. If a variable-speed or variable-frequency drive is used, the drive efficiency should be multiplied by that device's efficiency.
- COLUMN E - NUMBER OF FANS lists the number of identical fans included in this line.
- COLUMN F - PEAK WATTS is calculated as:

((BHP x Number of Fans x 746W/HP) / (Motor Efficiency, E_m *x Drive Efficiency,* E_d*)*where *BHP* (COLUMN B) is the design brake horsepower as described above, E_m (COLUMN C) and E_d (COLUMN D) are the efficiency of the motor and the drive, respectively, and

Number of Fans is the number of identical fans.

Totals and Adjustments

- TOTALS FANS SYSTEMS POWER is the sum of all PEAK WATTS from (COLUMN F). Enter sum in provided box at the right.
- SUPPLY DESIGN AIRFLOW (CFM) A box is provided at the bottom of the form (under COLUMN F) to identify the design airflow of the system.
- TOTAL FAN SYSTEM POWER INDEX, W/cfm is calculated by dividing the total PEAK WATTS (COLUMN F) by the total cfm. To

comply, total space-conditioning system power demands must not exceed 0.8 W/cfm for constant volume systems, or 1.25 W/cfm for VAV systems. See §144(c).

If filter pressure drop is greater than 1 inch W. C. Enter filter air pressure drop. SP_a on line 4 and total pressure drop across the fan SP_f on Line 5, otherwise leave blank and go to Line 7. See §144(c)3.

- SP_a is the air pressure drop across the air treatment or filtering system.
- SP_f is the total pressure drop across the fan.
- FAN ADJUSTMENT is the adjusted fan power index = 1-(SPa – 1)/ SPf.
- ADJUSTED FAN POWER INDEX is the total fan systems power index multiplied with the fan adjustment (Line 3 x Line 6). Note: TOTAL FAN SYSTEM POWER INDEX or ADJUSTED FAN POWER INDEX must not exceed 0.8 W/cfm, for Constant Volume systems or 1.25 W/cfm for VAV systems).

This bottom portion of the form is used to document the Electric Resistance Heating, Heat Rejection System and Air Cooled Chiller Limitations.

Electric Resistance Heat Limitation

In the capacity column, enter the total installed capacity of all electric heat exclusive of electric heat for heat pumps. If electric heat is used, identify in the exception column, which exceptions to §144(g) apply.

Enter notes to building department in the Notes column.

Centrifugal Fan Cooling Tower Limitation

In the capacity column, enter the total installed capacity of the centrifugal cooling towers. If centrifugal fan cooling towers are used, identify in the exception column which exceptions to §144(h) apply.

Enter notes to building department in the Notes column.

Air-cooled Chiller Limitation

In the capacity column, enter the total installed capacity of air-cooled chillers. In the second box, If the total installed capacity of the chiller plant is greater than 300 tons and the total installed capacity of air-cooled chillers is greater than 100 tons, identify in the exception column which exceptions to §144(i) apply.

Enter notes to building department in the Notes column.

4.11.8 Mechanical Inspection

The mechanical building inspection process for energy compliance is carried out along with the other building inspections performed by the building department. The inspector relies upon the plans and upon the MECH-1-C Certificate of Compliance form printed on the plans (See Section 4.11.1).

4.11.9 Acceptance Requirements

Acceptance requirements can effectively improve code compliance and help determine whether mechanical equipment meets operational goals and whether it should be adjusted to increase efficiency and effectiveness.

Acceptance tests are described in detail in Section 8.

Process

The process for meeting the acceptance requirements includes:

- Document plans showing thermostat and sensor locations, control devices, control sequences and notes,
- Review the installation, perform acceptance tests and document results, and
- Document the operating and maintenance information, complete installation certificate and indicate test results on the Certificate of Acceptance, and submit the Certificate to the building department prior to receiving a final occupancy permit.

Administration

The administrative requirements contained in the Standards require the mechanical plans and specifications to contain:

- Requirements for acceptance testing for mechanical systems and equipment shown in Table 4-6.

Table 4-6 – Mechanical Acceptance Tests

Variable Air Volume Systems
Constant Volume Systems
Package Systems
Air Distribution Systems
Economizers
Demand Control Ventilation Systems
Ventilation Systems
Variable Frequency Drive Fan Systems
Hydronic Control Systems
Hydronic Pump Isolation Controls and Devices
Supply Water Reset Controls
Water Loop Heat Pump Control
Variable Frequency Drive Pump Systems

- Requirement that within 90 days of receiving a final occupancy permit, record drawings be provided to the building owners,

- Requirement that operating and maintenance information be provided to the building owner, and
- Requirement for the issuance of installation certificates for mechanical equipment.

For example, the plans and specifications would require an economizer. A construction inspection would verify the economizer is installed and properly wired. Acceptance tests would verify economizer operation and that the relief air system is properly functioning. Owners' manuals and maintenance information would be prepared for delivery to the building owner. Finally, record drawing information, including economizer controller set points, must be submitted to the building owner within 90 days of the issuance of a final occupancy permit.

Plan Review

Although acceptance testing does not require that the construction team perform any plan review, they should review the construction drawings and specifications to understand the scope of the acceptance tests and raise critical issues that might affect the success of the acceptance tests prior to starting construction. Any construction issues associated with the mechanical system should be forwarded to the design team so that necessary modifications can be made prior to equipment procurement and installation.

Testing

The construction inspection is the first step in performing the acceptance tests. In general, this inspection should identify:

- Mechanical equipment and devices are properly located, identified, calibrated and set points and schedules established.
- Documentation is available to identify settings and programs for each device, and
- For air distribution systems, this may include select tests to verify acceptable leakage rates while access is available.

Testing is to be performed on the following devices:

- Variable air volume systems.
- Constant volume systems.
- Package systems.
- Air distribution systems.
- Economizers.
- Demand control ventilation systems.
- Variable frequency drive fan systems.
- Hydronic control systems.
- Hydronic pump isolation controls and devices.
- Supply water reset controls.
- Water loop heat pump control.

- Variable frequency drive pump systems.
- System programming.
- Time clocks.

Chapter 8 contains information on how to complete the acceptance forms. Example test procedures are also available in Chapter 8.

Roles and Responsibilities

The installing contractor, engineer of record or owners agent shall be responsible for documenting the results of the acceptance test requirement procedures including paper and electronic copies of all measurement and monitoring results. They shall be responsible for performing data analysis, calculation of performance indices and crosschecking results with the requirements of the Standards. They shall be responsible for issuing a Certificate of Acceptance. Building departments shall not release a final Certificate of Occupancy until a Certificate of Acceptance is submitted that demonstrates that the specified systems and equipment have been shown to be performing in accordance with the Standards. The installing contractor, engineer of record or owners agent upon completion of undertaking all required acceptance requirement procedures shall record their State of California Contractor's License number or their State of California Professional Registration License Number on each Certificate of Acceptance that they issue.

Contract Changes

The acceptance testing process may require the design team to be involved in project construction inspection and testing. Although acceptance test procedures do not require that a contractor be involved with a constructability review during design-phase, this task may be included on individual projects per the owner's request. Therefore, design professionals and contractors should review the contract provided by the owner to make sure it covers the scope of the acceptance testing procedures as well as any additional tasks.